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MEALINESS AND QUALITY OF DELICIOUS APPLES AS AFFECTED BY GROWING CONDITIONS, MATURITY AND STORAGE TECHNIQUES[1]

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The Delicious apple is grown in practically all the apple areas of North America, but in greatest volume in the Pacific Northwest in the State of Washington. Gourley and Howlett (13) show that Delicious is the most heavily planted, and continues to be the most heavily planted variety of apple in the United States of America. Detailed records of production by varieties are not available for either the United States or Canada. However, it has been reliably estimated (9) that the United States Delicious crop amounts to between 10 and 20% of the total apple production, probably averaging close to 15%. Taking the average yearly production of apples in the United States for 1934–38 as 125,310,000 bushels (9), 15% of this tonnage amounts to 18,796,000 bushels, a truly amazing figure. In the Okanagan Valley of British Columbia, Delicious is second in importance only to McIntosh.

Heavy plantings of Delicious apples indicate that a great and increasing volume of this variety will continue to be placed on the market. The reputation of Delicious has been built upon high dessert quality. However, much of the crop reaching consumers in recent years has been poor in quality and mealy in texture. The marketing of such poor quality fruit results in dissatisfied consumers and reduced demand.

EXPERIMENTAL

The experiments reported in this paper were conducted to ascertain the causes of mealiness and poor quality in Delicious apples, in the hope that such knowledge would lead to the delivery of this variety to the consumer in improved condition over a long marketing season, with consequent increased demand. Experiments were conducted over a 4-year period, 1937–41, with many hundreds of boxes of apples grown in the Okanagan Valley of British Columbia. In addition 1 year's work was carried out in Iowa with Iowa grown Delicious. The studies involved harvesting tests, different methods of storage, and physiological tests for recognizing and evaluating the progress of ripening in stored fruit. Controlled atmosphere storage of Delicious has been investigated in both Iowa and British Colum-Columbia. Chemical determinations were made of changes involved in the ripening of Delicious apples under different treatments.

[1] A condensation of a thesis submitted to the graduate faculty of Iowa State College, December 1941, in partial fulfilment of requirements for the degree of Doctor of Philosophy.

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Mealiness and Quality as Affected by Growing Conditions and Maturity

A comparison of Delicious grown in different orchards in different areas of the Okanagan Valley was made in 1937 and 1939 to ascertain the influence of environmental factors and cultural methods upon the quality of the fruit. Apples from 4 different orchards in each of 4 distinct districts were obtained during the commercial harvest period. Notes were made on cultural conditions under which the fruit was grown, maturity as judged by flesh colour, and quality after being held in cold storage at 32° F. for different periods of time.

There were notable differences in quality of fruit from different orchards but owing to the many soil, climatic and cultural factors involved, the data secured were insufficient to justify definite statements as to the exact causes of these differences in quality. However, with the fruit from each individual orchard there were obvious relations between maturity, mealiness and quality. Some data bearing on this are given in Table 1.

TABLE 1.—EFFECT OF ORCHARD VARIABILITY AND MATURITY UPON DEVELOPMENT OF MEALINESS AND QUALITY IN DELICIOUS APPLES AFTER 5½ MONTHS AT 32° F. AND 9 DAYS AT 60° F.

Grower	District	Colour of fruit	Size of fruit	Maturity	Flavour in prime condition	Observations 9 days after removal from 32° F. storage		Days to become overripe at 60° F.
						Mealiness	Flavour	
McTavish	Kelowna	Good	Large	Good	Good	Excessive	Stale	5
Barnard	Penticton	Good	Medium	Good	Fair	Excessive	Fair	5
Neil	Oliver	Good	Large	Good	Fair	Moderate	Fair	6
Webster	Vernon	Good	Small	Poor	Poor	None	Poor	*
Munson	Penticton	Fair	Medium	Poor	Poor	None	Poor	*
Gilmour	Oliver	Poor	Medium	Poor	Poor	None	Poor	*

* Fruit was disagreeable in flavour but difficult to say when it was overripe as it did not go mealy.

Fruit picked in an immature condition seldom became mealy, but was insipid in taste. On the other hand fruit picked in a fully mature condition developed good quality. This is in conformity with the results secured by Strachan (28). Both mature and immature picked fruit developed a stale disagreeable flavour when overripe.

Evidence was secured which indicates that weather conditions exert a marked influence on the maturity and quality of Delicious apples. Data regarding seasonal temperature are shown in Figure 1, which depicts total heat units in 10-day periods from May 10 to September 30 for 1939, 1940 and 1941. In calculating heat units for each 10-day period, a 50° F. base was used, and the number of hour-degrees in excess of 50° F. were totalled for each period.

In 1940 when maturity and quality of Delicious were excellent, the season was unusually warm from start to finish. On the other hand, in 1939, when maturity and quality were generally deficient in this variety, the season was unusually cool until mid-July, and after that of only moderate warmness. In 1941 when Delicious tended to be of inferior quality,

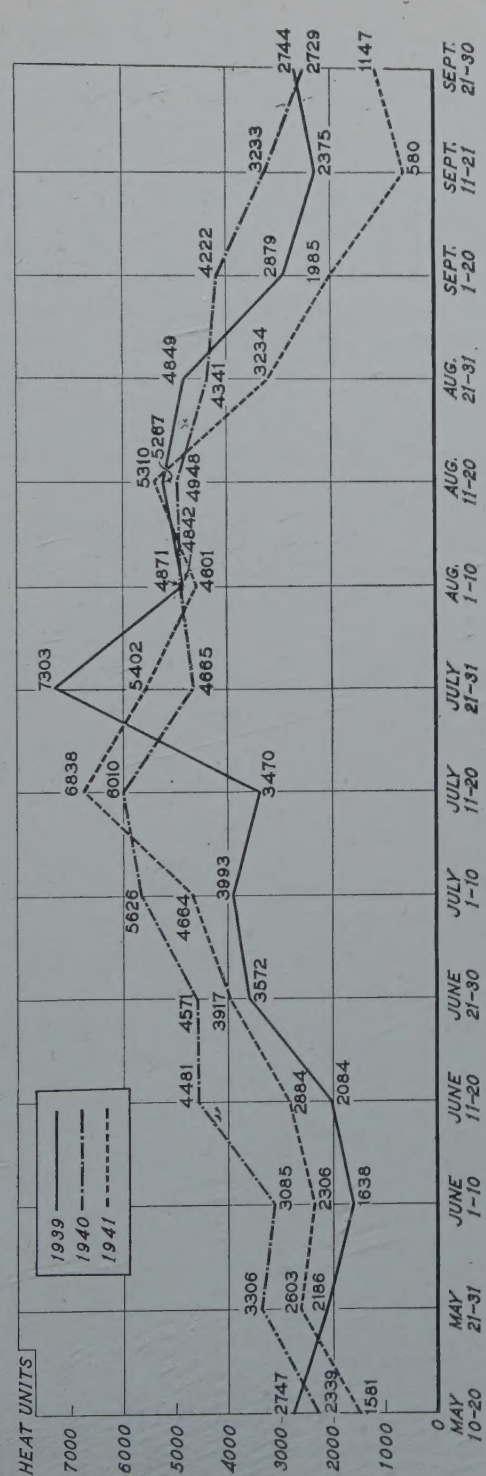

FIGURE 1. Heat units for 10-day periods from May 10 to September 30 for seasons 1939, 1940, and 1941. See text for discussion of relations between heat units, maturity and quality of Delicious apples.

early season temperatures were only moderately warm, while from the middle of August to the end of September, they were particularly cool. These observations suggest that there is a correlation between growing season temperatures, maturity, quality, and susceptibility to mealiness in Delicious apples.

MEALINESS AND QUALITY AS AFFECTED BY STORAGE TEMPERATURE

In the 1939–40 and 1940–41 seasons, Delicious of optimum maturity were held at 60°, 40°, and 32° F. from time of picking. The fruit was sampled at intervals to determine when it had become eating ripe and overripe. The data are presented in Table 2. On the basis of time required to reach certain stages of ripeness, these data indicate that the fruit ripened about three times as fast at 60° F. as at 40° F., and about 1.6 times as fast at 40° F. as at 32° F. Delicious were overripe in 5 to 6 weeks from picking when held at 60° F.; in 15 to 16 weeks when held at 40° F.; and in 24 to 27 weeks when held at 32° F.

TABLE 2.—EFFECT OF STORAGE TEMPERATURE ON RATE OF RIPENING IN DELICIOUS MEASURED BY CONDITION AT VARIOUS PERIODS IN STORAGE

Degree of ripeness	Time of ripening from time of picking		
	60° F.	40° F.	32° F.
	weeks	weeks	weeks
1939–40			
Eating ripe	2	7	12
Overripe	5	16	27
1940–41			
Eating ripe	2	6	9
Overripe	6	15	24

The effect of increasing periods of delay at packing house temperatures prior to cold storage upon softening of Delicious is shown in Table 3. The apples were picked on October 14, 1938, held at 60° F., and placed in 32° F. storage at weekly intervals thereafter. Flesh firmness was measured with the Ballauf pressure tester.

TABLE 3.—EFFECT OF DELAY AT 60° F. BEFORE COLD STORAGE UPON SOFTENING OF DELICIOUS. (FRUIT PICKED OCTOBER 14)

Tree No.	Date of storage at 32° F.	Firmness when stored	Tree No.	Date of storage at 32° F.	Firmness when stored
		lb.			lb.
653	October 15	18.2	654	October 15	18.1
	22	17.7		22	18.1
	29	14.9		29	15.7
	November 5	12.2		November 5	13.1

During the delayed storage period at 60° F. Delicious softened as much as 6 pounds in pressure in 3 weeks. Softening during the first week

was rather slight, but during the next 2 weeks softening was rapid. These data indicate the need for immediate cold storage of this variety.

One set of 8 boxes of apples was removed from cold storage to the ripening room (65° F.) on January 4, and similar sets removed subsequently on February 7, March 6, and April 3. When removed from storage the fruit was pressure tested and examined for flavour and texture. Judging by pressure test firmness, the data showed that Delicious softened as much in 3 weeks on the packing house floor as in 3 months cold storage at 32° F. Similar apples stored at 40° F. softened as much in 3 months as those stored at 32° F. did in 6 months. These data are in substantial agreement with the findings of Magness and Diehl (21) who reported that Delicious were softer at the end of 12 days at 70° F. than after 6 months at 32° F.

Delicious removed from 32° F. storage later than February remained in good condition only a little more than 1 week. Fruit given more than 1 week's delay at 60° F. before storage at 32° F. was definitely past its prime from February onwards. Fruit kept at 40° F. later than February was overripe upon removal from storage.

Respiration as Affected by Storage Temperatures

Respiration of fruits is an index of the biological activity of the tissue. Bigelow *et al.* (3) showed that within certain temperature limits rate of respiration increases according to Van't Hoff's Law. Respiration rate increases as temperature rises, and has been found to be associated with changes in starch, sugars, acid and pectin in ripening apples. Accordingly, the trend and degree of respiratory intensity in stored apples is of interest with reference to their storage capacity.

Respiration determinations were made with Delicious apples held continuously at 32°, 40°, and 60° F. from time of picking. Standard procedure was followed using about 8 kilograms of fruit enclosed in 4-gallon friction lid cans equipped with standard flow meters as described by Harding *et al.* (15) and Truog absorption towers. Respiration runs were $\frac{1}{2}$ hour or 1 hour in length and 0.1 N $Ba(OH)_2$ was used as the CO_2 absorbent.

Fruit held at 60° F. from time of picking showed a very rapid rise in respiratory intensity within 5 days of harvest after which respiration dropped gradually. This rise may have been the climacteric rise or simply a wound stimulus response resulting from picking. With apples held at 40° and 32° F. this rapid rise was not evident, but rather respiration carried on throughout the fall and winter more or less uniformly with the exception of a small rise toward the end of the season when the fruit was becoming fully ripe. Approximate respiration rates at different temperatures are shown in Table 4.

TABLE 4.—APPROXIMATE RESPIRATION RATES OF DELICIOUS APPLES HELD AT 32°, 40°, AND 60° F.

Temperature of storage	Respiration rate	Storage life of fruit	Sugars burned in respiration during storage
	cc. CO^2 per Kg. hr.	days	% of fresh weight
32° F.	2	175	.812
40° F.	3	105	1.01
60° F.	6	42	1.12

These data show that Delicious stored at 40° F. respired 1.5 times as fast as at 32° F., and at 60° F. 3.0 times as fast as at 32° F. These increases in respiration intensity with rising temperature are in agreement with those found by Magness *et al.* (22) but are not of quite as great a magnitude. The length of time the fruit remained in good eating condition amounted to 175, 105 and 42 days respectively for 32°, 40°, and 60° F. storage. Taking the sugar content of fresh Delicious apples as 11%, the data presented in Table 4 indicate that during the storage life of this variety only about 9% of the original respirable carbohydrate content is burned.

Pectin Content as Affected by Storage Temperatures

The softening of an apple is brought about largely by the hydrolysis of the insoluble protopectin in the cell walls and middle lamellae into soluble pectin. By losing the cell wall cementing material, the flesh of the apple gradually becomes softer and more palatable. The role of protopectin hydrolysis in softening of the apple has been demonstrated experimentally by Haller (14) Carré (6, 7) and Emmet (11). Similar results have been demonstrated with pears by Gerhardt (12) and with peaches by Appleman and Conrad (2).

In order to study the rate of soluble pectin formation in relation to temperature of storage, Delicious apples harvested at optimum maturity were held continuously at 3 temperatures, 60°, 40°, and 32° F. At succeeding periods in the storage life of the fruit, soluble pectin analyses were made and correlated with the condition of eating ripeness of the fruit at the time. Determination of soluble pectin was made according to the method outlined by Carré and Haynes (8). The data are given in Table 5.

TABLE 5.—EFFECT OF STORAGE TEMPERATURE UPON RATE OF SOLUBLE PECTIN FORMATION IN DELICIOUS APPLES

Weeks in storage	60° F.		40° F.		32° F.	
	Soluble* pectin	Condition of fruit	Soluble pectin	Condition of fruit	Soluble pectin	Condition of fruit
	mg.		mg.		mg.	
0	4.9		4.9		4.9	
1	6.6		—		—	
2	7.6	Ripe	—		—	
3	22.1		8.1		5.3	
4	22.8		—		—	
6	31.7	Mealy	10.7	Ripe	5.8	
9	—		11.8		9.1	Ripe
12	—		17.0		11.0	
15	—		19.9		12.2	
19	—		23.8	Mealy	13.4	

* Expressed in milligrams of calcium pectate per 16 cc. of juice.

These data indicate the rate of soluble pectin formation as influenced by temperature. At 60° F. there was about the same pectin value at the end of 4 weeks as there was in 19 weeks at 40° F. At the end of 19 weeks at 32° F. the apples had slightly more than one-half the soluble pectin content of similar fruit held at 40° F. for a similar period of time.

A correlation between the time at which the apples reached eating ripeness, and their rate of softening as measured by soluble pectin values, is also evident. Thus, Delicious apples when held continuously at 60° F. became eating ripe in about 2 weeks' time, and were distinctly mealy by the sixth week; when stored at 40° F. they became eating ripe in 6 weeks' time, and were definitely mealy by the nineteenth week; and when held at 32° F. were eating ripe in 9 weeks, and still in reasonably firm condition when removed from cold storage at the end of the nineteenth week.

Starch Disappearance as Affected by Storage Temperature

Most varieties of apples when picked at maturity contain heavy depositions of cellular starch. As apples ripen, the starch gradually disappears, having been hydrolyzed to sugar. Delicious apples have a particularly high starch content when picked. Disappearance of starch, as gauged by the starch-iodine reaction has been studied by a number of investigators as a guide to maturity at time of picking. The first work was done by Bigelow *et al.* (4) as early as 1905, and later work by Carne *et al.* (5). Davis and Blair (10) showed the value of the iodine test as a guide to picking certain apple varieties. Tiller (29) who worked with certain varieties including Delicious was inclined to discredit this test for practical purposes.

In this investigation disappearance of starch in Delicious apples was studied as an indicator of the progress of ripening in stored fruit. For each test 6 apples were cut equatorially and dipped for 2 minutes in a tray containing a weak iodine solution (1 gm. KI plus 25 gm. 1_2 made up to 100 cc.). The intensity of blue colouration of each lot of apples, indicating the amount of iodine present was compared with a chart of 8 photographed standards (see Figure 2). The experiments were carried out in 1939 and 1940 with fruit held continuously from picking at 60°, 40°, and 32° F.

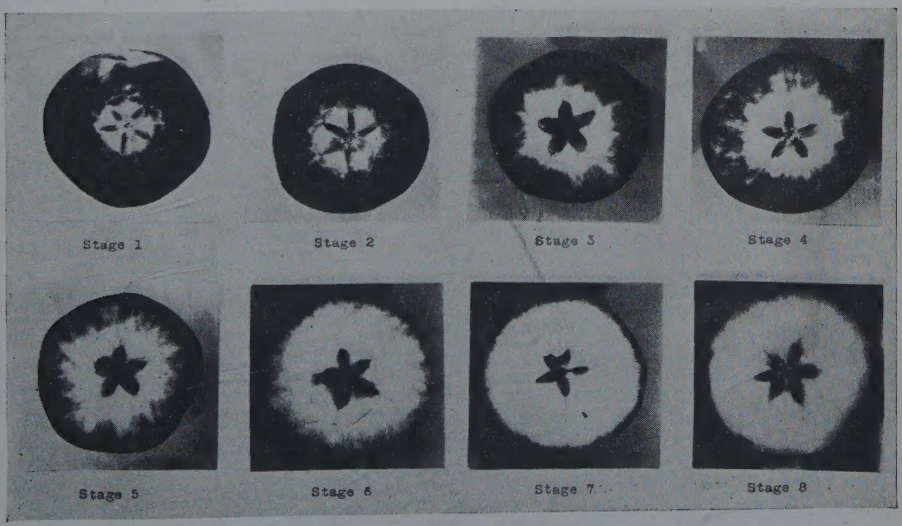

FIGURE 2. Progressive stages in starch hydrolysis of Delicious apples as indicated by the starch-iodine test. Stage 1 taken at time of picking, Stage 4 when first eating ripe, Stage 8 when fruit will soon become mealy.

With apples stored at 60° F. a starch-iodine test was made at weekly intervals; with apples stored at 40° and 32° F. at 3-week intervals. Results for the 1940–41 season only are given, as data for the 2 years corresponded closely.

In Table 6 it is evident that the rate of starch disappearance follows a very consistent trend, hastening as the temperature of storage increases. At 60° F., each succeeding week found the starch picture advanced about 1 stage. At 40° F. and 32° F. the change was not so rapid. However, it seemed consistent that when the fruit first reached eating ripeness, regardless of temperature, the starch-iodine picture was at stage 3 or 4. At these stages the fruit still contained considerable starch. However, the apples remained in firm eating condition until Stage 7 was reached where only a ring of starch remained around the outer periphery of the apples. Tests on numerous commercial lots indicate that when Delicious have reached stage 6 they are nearing the end of satisfactory storage life. The application of a chart such as this would prove of great assistance to a storage operator in judging the condition of his Delicious stocks. By cutting samples of apples during the storage season and applying the iodine test, the stage of ripeness of the fruit and its probable holding life can easily be judged.

TABLE 6.—EFFECT OF STORAGE TEMPERATURE UPON RATE OF STARCH DISAPPEARANCE AND RIPENING IN DELICIOUS APPLES

Weeks in storage	60° F.		40° F.		32° F.	
	Starch-iodine number	Condition of fruit	Starch-iodine number	Condition of fruit	Starch-iodine number	Condition of fruit
0	2		2		2	
1	3		–		–	
2	4	Ripe	–		–	
3	5		2 – 3		2	
4	6		–		–	
5	6		–		–	
6	7	Mealy	3	Ripe	2 – 3	
9	–		4		3	Ripe
12	–		5 – 6		4	Ripe
15	–		7		5 – 6	Ripe
19	–		–	Mealy	7	Ripe

Mealiness and Quality of Delicious as Affected by Controlled Atmospheres

Controlled atmosphere storage (gas storage) has received considerable attention in recent years as a means of prolonging the storage life of apples. The method was first propounded by Kidd and West (17, 19, 20). The experiments of Kidd and West showed that atmospheres enriched in carbon dioxide and low in oxygen produced by the respiration of fruit in enclosed refrigerated chambers, retarded changes in green skin colour, slowed up ripening, and prolonged storage life. By storing Bramley Seedling at 40° F. under gas storage, low temperature internal browning injury brought about by 32° F. air storage was avoided, and keeping life was as great or greater than at 32° F. Further experiments employing

atmospheres very low in both oxygen and carbon dioxide produced by fruit respiration, plus chemical absorption of excess carbon dioxide, are reported by Kidd and West (18) for the Lane's Prince Albert variety. Favourable results with controlled atmosphere storage have been reported in America by Allen and McKinnon (1) with Yellow Newtown, and by Smock and Van Doren (27) and Phillips (23) with McIntosh.

No data were available on the response of Delicious to controlled atmosphere storage, so a number of experiments were undertaken to find if the keeping life of this variety could be lengthened, and development of mealiness delayed, by the use of this storage method.

Three seasons' work were undertaken studying controlled atmospheres. In the first season 3 concentrations of carbon dioxide for Delicious apples were studied, (5.0, 7.5 and 10.0%) with fruit in 4-gallon cans held at both 32° and 40° F. Medium sized Fancy unwrapped apples were used. The fruit was allowed to build up the desired carbon dioxide concentrations in the cans, and the cans were then ventilated every other day, after a gas analysis of the contents had been made, so as to hold the carbon dioxide at a constant level. After 6 months' storage the apples were removed to the 60° F. ripening room for examination and comparison with air-stored fruit. The data obtained after 1 week at 60° F. are shown in Table 7.

TABLE 7.—INFLUENCE OF REGULATED VENTILATION CONTROLLED ATMOSPHERE STORAGE ON DELICIOUS HELD AT 32° F. AND 40° F. FOR 6 MONTHS

Temperature	Lot no.	Gas mixture		Firmness	Scald	Flavour	Condition
		O_2	CO_2				
				lb.	%		
32° F.	13	15	5	12.0	32	Off, stale	Mealy
	15	12.5	7.5	12.0	15	Off, stale	Slightly mealy
	17	10.0	10.0	11.8	12	Off, stale	Slightly mealy
	Check	Air	—	14.4	5	Fair	Firm
40° F.	7	15	5	9.7	66	Off, stale	Mealy
	9	12.5	7.5	10.0	50	Off, stale	Mealy
	11	10.0	10.0	11.0	52	Off, stale	Mealy
	Check	Air	—	9.6	—	Off, stale	Mealy

The data in Table 7 indicate that fruit held in air at 32° F. for 6 months was distinctly firmer than that held under additional carbon dioxide, while at 40° F. there was not much difference in firmness since the fruit had all softened to about its limit by the time it was removed from storage. The apples stored at 32° F. in all 3 concentrations of carbon dioxide were definitely soft and mealy and off-flavour after 1 week out of cold storage, whereas air-stored fruit was firm and fair in flavour. In the lots held at 40° F. for 6 months all fruit, whether stored in air or under carbon dioxide atmospheres, was mealy and past prime.

It is interesting to note that there was a heavy incidence of a peculiar type of skin scald on the fruit stored under carbon dioxide, especially at 40° F. Check fruit showed but little scald. This particular type of scald tended to cause the skin of affected apples to set in hard wrinkles. It can probably be considered a form of carbon dioxide injury.

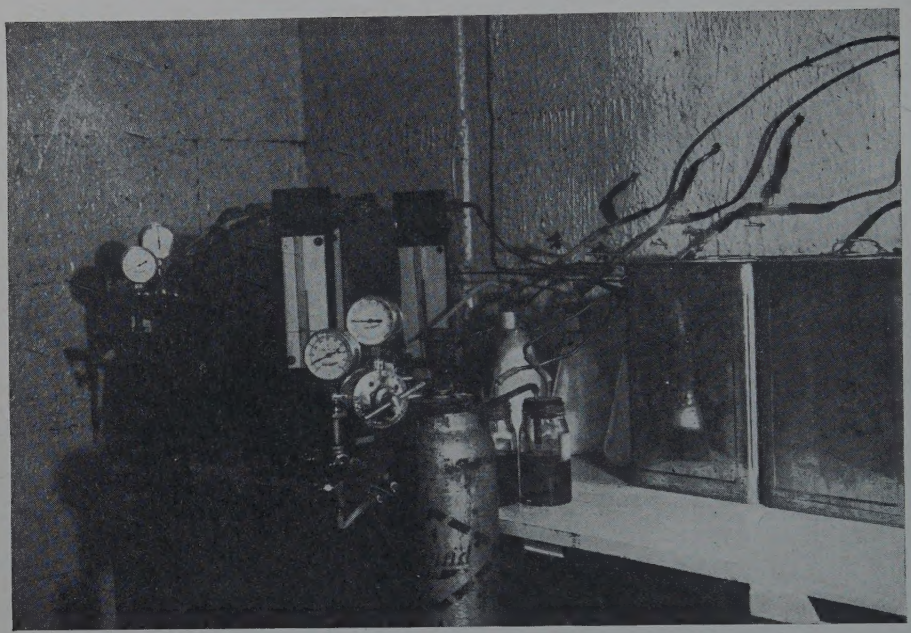

FIGURE 3. Gas mixing apparatus with delivery lines leading off to the various cans of enclosed fruit. Carbon dioxide cylinder front; nitrogen cylinder extreme left; oxygen cylinder at back.

Further experiments involving the storage of Delicious iu controlled atmospheres were conducted in 1938–39 at the Iowa State College and in 1940–41 at the Dominion Experimental Station, Summerland, B.C. In both seasons 3 different atmospheres were used with fruit held at temperatures of 32° and 40° F. These atmospheres were made up from cylinders of compressed gas with the aid of precision pressure reducers, flow meters and bubble counters for adjustment of rates of flow. The gas mixtures were flushed continuously through the fruit containers at a rate sufficient to change the atmospheres twice per day. Once set in operation the equipment (see Figure 3), gave exceptional uniformity in gas mixtures. The gas content within the experimental fruit containers was checked twice weekly with an Orsat gas analyser. The following gas mixtures were used.

GAS MIXTURE USED IN CONTROLLED ATMOSPHERIC EXPERIMENTS

Gas mixture	Percentage of gases		
	CO_2	O_2	N_2
	%	%	%
1	5.0	2.5	92.5
2	0.0	2.5	97.5
3	5.0	25.0	70.0
4	0.0	20.0	80.0

The fruit selected for the experiments was of medium size and Extra Fancy quality. It was placed under refrigeration, according to the different treatments, within a day of picking. Since the results for the 2 seasons corresponded rather closely, for the sake of brevity the results for 1490–41 only are presented.

In this experiment the apples were harvested October 9 and stored October 11. The fruit was removed from storage for examination on February 17. When removed from storage, and 17 days later on March 6, pressure tests and eating tests were made and acidity and soluble pectin content determined. In addition 100-gram representative samples of tissue from 15 fruits were preserved in boiling 80% ethyl alcohol for future analysis. At the time the fruit was removed from storage the iodine test was applied to the different lots to ascertain the presence of unhydrolyzed starch.

To secure evidence regarding quality and condition after removal from storage, the various lots of fruit, along with control samples stored in air, were marked with reference numbers and presented to a panel of 7 judges for rating. In the following table firmness of fruit by pressure test and flavour and ground colour of skin as determined by the judges are given. Flavour is based on a score of 10 being perfect.

TABLE 8.—EFFECT OF CONTROLLED ATMOSPHERE STORAGE UPON QUALITY AND CONDITION OF DELICIOUS APPLES WHEN REMOVED FROM STORAGE FEBRUARY 17

Treatment No.	Treatment	Storage temperature	Firmness	Flavour 1 – 10	Ground colour
		°F.	lb.		
1a	2.5% O_2	40	12.4	7.6	Light green
1b	5.0% CO_2	40	12.9	6.6	Light green
1c	92.5% N_2	32	13.6	5.0	Light green
1d		32	13.8	6.8	Light green
2a	2.5% O_2	40	12.0	8.6	Light green
2b	0.0% CO_2	40	11.7	6.3	Light green
2c	9.5% N_2	32	12.5	6.3	Light green
2d		32	13.3	7.1	Light green
3a	25.0% O_2	40	11.3	6.0	Yellow
3b	5.0% CO_2	40	10.2	4.1	Yellow
3c	70.0% N_2	32	11.6	6.3	Yellow
3d		32	11.4	8.2	Yellow
4a	Air	40	9.2	5.1	Yellow
4b		32	10.8	5.2	Yellow

It is interesting to note that at both 32° and 40° F. treatments 1 and 2 resulted in fruit of superior firmness, whereas treatments 3 and 4 gave fruit judged to be much softer; in fact turning mealy. On the average, flavour was also judged to be better in the first 2 than in the last 2 treatments, with the exception of fruit in 3d which for some reason, not confirmed in later examinations, received a very high rating. The pronounced stale flavour characteristic of overripe Delicious was obvious in many apples from treatments 3 and 4. However, with the exception of the fruit in 1c, which had a pronounced off-flavour for a day or two after removal to air controlled atmosphere treatments did not produce any undesirable

off-flavours in the fruit. No apple scald developed in any of the apples whether oil wrapped or unwrapped. The effect of higher oxygen concentration upon changes in skin colour was noted in treatments 3 and 4 which showed fruit of yellow ground colour as compared with light green colour in the low oxygen treatments (1 and 2).

Pectin, Starch, and Acidity as Affected by Controlled Atmospheres

Possibly the most accurate test for changes in firmness and cell wall structure in fruit is the determination of degree of protopectin hydrolysis to the soluble pectin form, (6, 7, 11, 14) which indicates the degree to which the middle lamellae of the cell walls have become hydrolyzed and broken down, and consequently the progress of softening of the flesh. Acidity changes as a rule give some indication of progress of ripening, since acid tends to disappear during the ripening process. This has been shown by Magness and Diehl (21) who found that after 6 months at 32° F. Delicious lost roughly one-third of its acid. Plagge (24, 25) found a decrease in acid varying with length and temperature of storage. Starch hydrolysis also provides a useful guide as to the stage of ripeness attained since complete absence of starch (as judged by the iodine reaction) is associated with full ripeness. Data concerning the influence of controlled atmosphere storage on pectin, starch, and acidity are presented in Table 9.

It is clearly indicated by the data in Table 9 that protopectin hydrolysis of cell wall thickenings to the soluble pectin form was markedly retarded by each of the three controlled atmospheres in comparison with air storage.

TABLE 9.—EFFECT OF CONTROLLED ATMOSPHERE STORAGE UPON SOLUBLE PECTIN CONTENT ACIDITY, AND STARCH VALUES OF DELICIOUS APPLES AT TIME OF REMOVAL TO AIR, FEBRUARY 18, 1941

Treatment No.	Treatment	Storage temperature	Soluble pectin*	Acidity		Starch-iodine reaction stage (see Figure 2)
				pH	Total†	
		°F.	mg.		cc.	
1a	2.5% O_2	40	6.2	4.42	5.7	7
1b	5.0% CO_2	40	6.8	4.36	5.6	7
1c	92.5% N_2	32	6.4	4.43	5.7	7
1d		32	5.4	4.41	6.0	7
2a	2.5% O_2	40	4.2	4.44	5.5	7
2b	0.0% CO_2	40	5.2	4.41	5.8	7
2c	97.5% N_2	32	3.2	4.48	5.8	6
2d		32	4.5	4.46	5.8	6
3a	25.0% O_2	40	9.3	4.47	4.8	8
3b	5.0% CO_2	40	8.3	4.43	4.8	8
3c	70.0% N_2	32	5.2	4.43	4.9	7
3d		32	5.4	4.49	5.2	7
4a		40	24.6	4.63	5.0	8
4b	Air	40	23.1	3.52	5.2	8
4c		32	11.1	4.49	5.6	7
4d		32	15.7	4.55	5.6	7
Check	Fruit at picking		4.9	4.32	7.7	2

* Expressed as calcium pectate per 16 cc. juice.
† Expressed as 0.05 *N* NaOH to titrate 12.5 cc. juice diluted to 50 cc.

In fruit stored under controlled atmospheres soluble pectin values at time of removal were only slightly higher at 40° F. than at 32° F., whereas in the air stored fruit soluble pectin values at 40° F. were approximately double those at 32° F.

Fruit stored in controlled atmosphere treatments 1 and 2 showed close to the same soluble pectin value (4.9 mg.), at time of removal to air, as found at time of picking. In other words, practically no protopectin hydrolysis had taken place in the fruit stored in controlled atmospheres during a storage period of over 4 months. Van Doren (30) likewise reports a diminished rate of softening and protopectin hydrolysis in McIntosh apples stored in controlled atmospheres as compared with air, while similar results for other fruits have been reported by Smock and Allen (26).

Starting with an initial active acidity value (pH) of 4.32 and total acidity value of 7.7 at time of picking, by the end of the storage period these values had dropped to around pH 4.45 and 5.5 for total acidity. The air stored fruit at 40° F. and the fruit from treatment 3 with high oxygen showed the greatest acid losses. It will be noted that results with duplicate "a" and "b" treatments did not always check. This is probably due to variability in the samples.

Apples from each lot were cut and dipped in iodine solution, and the amount of starch present recorded. Traces of starch in the outer periphery of the cortex were noted in most lots, but only in samples 2c and 2d were any appreciable quantities of starch present. Eating tests and pectin values suggested also that these 2 lots were least advanced in degree of ripeness.

Nine days after the Delicious were removed from controlled atmosphere storage to air at 65° F. they were again examined for eating quality and firmness. Lots 1 and 2 had retained their firmness and crispness to a

TABLE 10.—CONDITION OF DELICIOUS APPLES 17 DAYS AFTER REMOVAL FROM CONTROLLED ATMOSPHERE STORAGE TO AIR AT 65° F., MARCH 6, 1941

Treatment No.	Treatment	Storage temperature	Flavour	Mealiness	Firmness
		°F.			
1a	2.5% O_2	40	5	Excessive	9.9
1b	5.0% CO_2	40	5	Excessive	8.5
1c	92.5% N_2	32	5	Excessive	9.6
1d		32	5	Excessive	9.2
2a	2.5% O_2	40	5	Excessive	9.1
2b	0.0% CO_2	40	6	Moderate	9.6
2c	97.5% N_2	32	7	Moderate	10.5
2d		32	7	Moderate	9.9
3a	25.0% O_2	40	5 stale	Excessive	7.7
3b	5.0% CO_2	40	5 stale	Excessive	7.9
3c	70.0% N_2	32	5	Excessive	9.2
3d		32	5	Excessive	8.6
4a		40	3 stale	Excessive	8.7
4b	Air	40	3 stale	Excessive	8.7
4c		32	4 stale	Excessive	8.8
4d		32	4 stale	Excessive	8.8

marked degree whereas Lot 3 was going mealy and the air stored samples at 32° and 40° F. were definitely mealy. Moreover, the air stored samples, particularly those held at 40° F., had taken on the typical stale overripe Delicious flavour.

Seventeen days after removal from storage the fruit was again given an extensive examination. Pressure tests and chemical determinations were made similar to those made at time of removal from storage. Results of sampling tests to determine flavour, mealiness, and firmness are given in Table 10.

These data indicate that the initial advantage in firmness of the fruit stored in controlled atmospheres had largely disappeared by March 6, seventeen days later, All lots except those receiving treatment 2 were definitely mealy, and a stale objectionable aldehyde flavour had developed in lots 3a, 3b, and 4a, 4b, 4c, and 4d. The fruit from lots 2b, 2c, and 2d was considerably less mealy than the other lots and superior in flavour.

As indicated by pressure tests, the fruit which received treatment 2 was also firmer than the other lots. The fruit receiving the high oxygen treatment at 40° F. (lots 3a, 3b) was decidedly the softest of all 3 treatments. Air stored fruit was softer than fruit given treatments 1 and 2.

When fruit was examined on March 6, seventeen days after removal from storage, soluble pectin and acidity values were again determined. These data follow in Table 11.

By comparing these data with those given in Table 9, striking changes are evident, especially the pectin values of fruit receiving treatments 1, 2, and 3 which increased greatly during the 17 days at 65° F. The fruit

TABLE 11.—EFFECT OF CONTROLLED ATMOSPHERE STORAGE UPON THE SOLUBLE PECTIN CONTENT AND ACIDITY VALUES OF DELICIOUS APPLES 17 DAYS AFTER REMOVAL FROM STORAGE, MARCH 6, 1941

Treatment No.	Treatment	Storage temperature	Soluble pectin*	Acidity	
				pH	Total†
		°F.	mg.		cc.
1a	2.5% O_2	40	26.7	4.70	5.3
1b	5.0% CO_2	40	23.5	4.66	5.0
1c	92.5% N_2	32	25.6	4.71	5.9
1d		32	28.7	4.62	5.8
2a	2.5% O_2	40	2.35	4.69	5.6
2b	0.0% CO_2	40	27.1	4.71	5.0
2c	97.5% N_2	32	22.4	4.72	5.1
2d		32	21.6	4.72	4.9
3a	25.0% O_2	40	38.5	4.77	4.8
3b	5.0% CO_2	40	37.9	4.72	4.9
3c	70.0% N_2	32	25.1	4.76	5.6
3d		32	33.6	4.74	4.7
4a		40	29.9	4.74	5.2
4b	Air	40	29.4	4.72	5.1
4c		32	30.2	4.88	4.6
4d		32	32.1	4.81	5.5

* Expressed as calcium pectate per 16 cc. juice.
† Expressed as 0.05 *N* NaOH to tritrate 12.5 cc. juice diluted to 50 cc.

given treatment 3 and stored at 40° F. showed by far the highest soluble pectin content, and this was in agreement with the pressure test determinations taken on this fruit at that time. With the check lots stored in air the pectin content of the 32° F. fruit which had been quite low on removal from cold storage, rose rapidly with the result that at the close of the 17-day period it was about the same as the 40° F. fruit, and slightly higher than the fruit receiving treatments 1 and 2.

Active acidity and total acidity decreased somewhat, but these changes did not appear to be correlated significantly with any particular storage treatment.

Sugar Content and Weight of Alcohol-insoluble Residue as Affected by Controlled Atmospheres

To determine what changes had taken place in the sugar content of the fruit stored under different atmospheres, duplicate analyses from each lot were made for reducing sugar and sucrose, according to the Munson-Walker-Bertrand method. Sugar was extracted from 100-gram composite tissue samples preserved in 80% ethyl alcohol, by 15 successive leachings with boiling 80% alcohol. The dry weights of the alcohol-leached tissue samples were obtained, principally to ascertain the decrease in insoluble residue between harvest time and the time the fruit was removed from storage in February. The difference, which is large, can be assumed without appreciable error to be due to starch present at picking, but almost entirely hydrolyzed to glucose during storage. These data are given in Tables 12, 13 and 14.

TABLE 12.—EFFECT OF CONTROLLED ATMOSPHERE STORAGE ON SUGAR CONTENT OF DELICIOUS APPLES WHEN REMOVED FROM STORAGE, FEBRUARY 17, 1941

Treatment No.	Treatment	Storage temperature	Percentage sugar (fresh weight basis)		
			Reducing	Sucrose	Total
		°F.	%	%	%
Fall, 1941, at picking			6.65	2.52	9.17
1a	2.5% O_2	40	9.11	1.52	10.63
1b	5.0% CO_2	40	9.57	1.60	11.10
1c	95.5% N_2	32	8.64	2.24	10.88
1d		32	8.94	2.60	11.54
2a	25.0% C_2	40	9.36	2.16	11.52
2b	0.0% CO_2	40	9.11	1.80	10.91
2c	97.5% N_2	32	8.78	2.36	11.14
2d		32	8.78	2.20	10.98
3a	25.0% O_2	40	9.32	1.60	10.92
3b	5.0% CO_2	40	9.36	1.24	10.60
3c	70.0% N_2	32	8.69	2.36	11.05
3d		32	8.57	2.64	11.21
4a		40	8.27	2.72	10.99
4b	Air	40	—	—	—
4c		32	8.94	2.12	10.06
4d		32	9.32	2.40	11.72

From Table 12 it is evident that there was some variation between lots as to reducing sugar and sucrose content, but there does not seem to be any significant effect that could be attributed to the treatments themselves. Rather it would appear that variations existing between duplicate samples (i.e. "a" and "b", "c" and "d" samples), and different treatments (i.e. 1, 2, 3, and 4) could be more reasonably assigned to slight variations in experimental samples.

Unless respiration rates were very markedly reduced by controlled atmospheres, not much change in total sugar content could be expected, for by calculation it has been shown elsewhere in this report that a Delicious apple loses only about 9.0% of its sugar content through respiration during a period of 6 months' storage at 32° F. It has been shown by Kidd and West (16) that there is some reduction in respiration rate of apples in controlled atmosphere storage.

It does seem fairly consistent, however, that the sucrose content of apples stored at 32° F. was a little higher than that of those at 40° F. It is interesting also to note the low total sugar value for the sample taken at picking. This value (6.65%) is low in comparison with the samples taken after storage, because in these samples, approximately 2.5% of starch present in the apples at picking had been hydrolyzed over to reducing sugar.

In Table 13 are shown the sugar values for the different samples 17 days after removal from storage. These figures again indicate little significant difference between treatments, and on the whole tend to show a slightly higher sugar content than at the time of removal from storage, probably because of a small degree of shrivelling.

TABLE 13.—EFFECT OF CONTROLLED ATMOSPHERE STORAGE ON SUGAR CONTENT OF DELICIOUS APPLES 17 DAYS AFTER REMOVAL FROM STORAGE, MARCH 6, 1941

Treatment No.	Treatment	Storage	Percentage sugar (fresh weight basis)		
			Reducing	Sucrose	Total
		°F.	%	%	%
1a	2.5% O_2	40	10.20	1.68	11.88
1b	5.0% CO_2	40	9.66	2.16	11.82
1c	92.5% N_2	32	9.32	2.20	11.52
1d		32	9.36	2.08	11.44
2a	2.5% O_2	40	9.70	1.68	11.38
2b	0.0% CO_2	40	9.83	2.04	11.87
2c	97.5% N_2	32	9.45	1.84	11.29
2d		32	8.94	2.68	11.62
3a	25.0% O_2	40	9.20	1.88	11.08
3b	5.0% CO_2	40	9.32	2.08	11.40
3c	70.0% N_2	32	9.36	1.84	11.20
3d		32	9.49	1.92	11.41
4a		40	10.20	1.56	11.76
4b	Air	40	9.37	2.04	11.41
4c		32	9.37	2.08	11.45
4d		32	8.36	3.20	11.56

In Table 14 the alcohol-insoluble residue after extraction of the 100-gram sample of tissue is shown. It is apparent from these data that the alcohol-insoluble residue of the fruit was approximately 2%, subject to variations between samples. The weights of the residue on March 6 were consistently less than on February 17, this loss probably being due to pectin compounds in the cell walls being hydrolyzed over to the soluble form, as reported under pectin analyses. The comparison with the sample taken in the fall at time of picking (4.32%) indicates that roughly 2.5% of the starch present at harvest time was hydrolyzed during storage to reducing sugar.

TABLE 14.—EFFECT OF CONTROLLED ATMOSPHERE STORAGE UPON INSOLUBLE RESIDUE REMAINING AFTER ALCOHOL EXTRACTION OF APPLE TISSUE FOR REMOVAL OF SUBSTANCES SOLUBLE IN 80% ETHYL ALCOHOL

Treatment No.	Treatment	Storage temperature	Percentage insoluble residue in samples preserved on	
			Feb. 17	March 6
			%	%
1a	2.5% O_2	40	1.95	1.88
1b	5.0% CO_2	40	2.01	1.80
1c	92.5% N_2	32	2.01	1.84
1d		32	2.16	1.87
2a	2.5% O_2	40	1.95	1.78
2b	0.0% CO_2	40	1.97	1.75
2c	97.5% N_2	32	1.97	1.85
2d		32	2.00	1.84
3a	25.0% O_2	40	1.95	1.78
3b	5.0% CO_2	40	1.80	1.74
3c	70.0% N_2	32	2.07	1.80
3d		32	1.84	1.78
4a		40	1.81	1.83
4b	Air	40	2.00	1.88
4c		32	2.02	1.87
4d		32	2.26	1.87

NOTE: A check sample analysed at harvest time contained 4.32% insoluble residue.

SUMMARY

This investigation dealing with harvesting and storage of Delicious apples was conducted between 1937 and 1941. A great volume of fruit was examined from growers' orchards, and from commercial cold storage plants of the apple growing districts of the Okanagan Valley of British Columbia. One year's work was carried out in Iowa with Iowa-grown Delicious. The studies involved harvesting tests, different methods of storage, and physiological tests for recognizing and evaluating the progress of ripening in stored fruit. Controlled atmosphere storage for Delicious was investigated in both Iowa and British Columbia. Chemical determinations were made to discover changes in sugar, starch, acid and pectin during the ripening of Delicious apples under different treatments. The results are summarized as follows:

1. Delicious apples harvested in different orchards in different districts showed great variability in maturity and quality.

2. Apples picked immature never developed true Delicious flavour, but seldom turned mealy, even after prolonged storage; apples picked mature had good flavour, but tended to become mealy soon after ripening unless stored immediately at 32° F.

3. Delicious, whether mature or immature at harvest, acquired a stale disagreeable flavour when over-ripe.

4. Seasonal weather conditions greatly influenced quality in Delicious. In the cool seasons of 1939 and 1941 maturity and quality were generally poor; in the hot season of 1940, excellent.

5. After harvest Delicious became *eating ripe* in 2 weeks at 60° F.; in 6 to 7 weeks at 40° F.; and in 9 to 12 weeks at 32° F.

6. Delicious apples were *overripe* and mealy in 5 to 6 weeks from picking when held at 60° F., in 15 to 16 weeks when held at 40° F., and in 24 to 27 weeks when held at 32° F.

7. Delayed storage at 60° F. greatly reduced subsequent storage life.

8. Delicious softened as much in 3 weeks at 60° F. as in 3 months at 32° F. At 40° F. Delicious softened as much in 3 months as apples stored at 32° F. for 6 months.

9. In Delicious held at 60° F., respiration intensity reached its peak about 5 days after picking; fruit stored at 40° and 32° F. showed no distinct peak.

10. Respiration rate at 60° F. was double that at 40° F. and 3 times that at 32° F. Sugar losses through respiration during the storage life of the fruit amounted to roughly 1% of the fresh weight at picking.

11. Hydrolysis of protopectin to soluble pectin in Delicious apples closely parallelled rate of ripening at different temperatures.

12. Disappearance of starch as judged by the starch-iodine reaction proved a reliable index of degree of ripening in storage. For this purpose, a set of 8 photographed standards is presented showing progressive decrease in starch content of Delicious apples during ripening.

13. Delicious stored in "natural build-up" carbon dioxide concentrations of 5.0, 7.5, and 10.0% at 32° and 40° F. actually became mealy faster than similar fruit stored in air.

14. These atmospheres induced severe development of a peculiar type of skin scald, especially at 40° F.

15. Storage of Delicious apples in an atmosphere of 2.5% oxygen and 97.5% nitrogen at 40° and 32° F. retarded softening, inhibited changes in ground colour of skin, and greatly improved keeping quality over fruit stored in air at 32° F. When removed from storage in February, soluble pectin values of the fruit were about the same as at time of picking. Keeping life at 65° F. after removal was prolonged at least 10 days as compared with similar fruit stored in air at 32° F.

16. An atmosphere of 2.5% oxygen, 5.0 per cent carbon dioxide, and 92.5% nitrogen gave nearly as good results as the 2.5 : 97.5 oxygen-nitrogen mixture.

17. Storage of Delicious in an atmosphere containing 25.0% oxygen, 5.0% carbon dioxide, and 70.0% nitrogen caused the fruit to go mealy and ripen more rapidly than in air.

18. Much greater differences in storage life of Delicious were noted between 32° and 40° F. storage in air, than between 32° and 40° F. storage in controlled atmospheres.

19. The only significant changes determined in chemical composition of fruit stored in controlled atmospheres as compared with air, involving analyses for sugars, starch, acid, and pectin, were the differences in degree of protopectin hydrolysis, which reflected the amount of softening which had taken place.

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AN OUTBREAK OF COMMON ROOT ROT IN SOUTHWESTERN SASKATCHEWAN IN 1942[1]

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Following receipt of a number of reports and specimens indicating a severe root-rot condition of wheat in the southwestern part of Saskatchewan, the writers visited the area between Ponteix and Cadillac on August 31, soon after the crops were ripe and ready to be cut.

On account of a period of wet weather, the straw and heads of the crops were somewhat weathered and darkened by the growth of saprophytic fungi. From the roadside, varying proportions of the fields in small to large patches were very noticeably darker in colour than the normal areas. On entering the fields, the plants in these patches were found to be definitely stunted, much weathered, and in some cases considerably broken over or bent down as compared with normal areas (see Figure 1). The

FIGURE 1. Photographs of the paired samples from two fields. In each pair, the one on the right is from the severely diseased area. Note the stunting of the plants and the darker colour of the straw.

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discoloration of the straw and heads was due to an abundant growth of dark-coloured moulds. While the writers did not notice any odour, possibly due to a heavy rain the night before followed by cool temperatures, several correspondents had described a musty or mouldy odour from the fields. The grain was found to be shrunken. On pulling up plants, there was apparently considerable infection of the basal parts of the stem by the common root-rot fungi. In general, the diseased areas were located on slopes rather than on high or low lying parts of the field.

The disease was identified in the field, later confirmed in the laboratory, as a form of common root rot in which premature ripening or drying up of the plants was a prominent symptom. A severe necrosis of the tissues of the crown and subcrown internode was apparently caused by the common root-rot fungi, *Helminthosporium sativum*, P.K. and B., and *Fusarium* spp.

Geographic Distribution

No attempt was made to survey the whole area in which the disease occurred in severe form. However, from the reports received, supported in several instances by specimens of diseased plants, it was possible to determine the general area involved. Apparently numerous fields in a roughly triangular area with Cabri, Eastend, and Glentworth at the angles showed more or less of the disease. About 4,000 square miles are included in this region. Figure 2 shows the location of this area in relation to the agricultural portion of Saskatchewan.

FIGURE 2. Outline map of the southern part of Saskatchewan showing the approximate areas (stippled) in which the 1942 outbreak of common root rot was most severe.

STUDY OF SAMPLES

Paired samples of the crop were taken in 6 fields. The samples were collected from measured square yard areas, 1 from a diseased and 1 from a normal-appearing area not more than 4 or 5 feet apart. In addition, 2 other fields were similarly sampled but not from measured areas. These samples were taken to the laboratory for study. Yields per acre were calculated from the square yard samples, and the number of plants, the yield per plant, and thousand kernel weights were recorded. In addition, the amount of common root rot present in each sample was estimated by 2 different methods.

Yields

The yields of threshed grain are given in Table 1, in bushels per acre.

In every pair of samples, the diseased sample gave decidedly the lower yield. While the estimation of yields from single square yard areas is admittedly subject to large errors, the consistency of the results over the 6 fields and the wide differences indicate that the differences are significant.

TABLE 1.—YIELDS IN BUSHELS PER ACRE

Class	Field number						Class means
	3	4	5	6	7	8	
Healthy*	26	28	29	30	33	40	31
Diseased†	15	15	14	19	14	17	16

* The term "healthy" used here or hereafter is not to be taken too literally, since considerable disease was present, as is evident in Table 7.

† The term "diseased" is used to refer to the very discoloured patches of crop.

Yields per Plant

Since in 2 fields samples were taken from diseased and healthy patches without regard to area, the yields can be given only on a single plant basis. In these cases, the number of plants in each sample was over 100 and under 170. Table 2 gives the average yield per plant for all fields sampled.

TABLE 2.—YIELDS IN GRAMS ON A SINGLE PLANT BASIS

Class	Field number								Class means
	1	2	3	4	5	6	7	8	
Healthy	1.14	1.06	1.01	1.44	1.58	1.00	1.15	1.16	1.19
Diseased	0.58	0.77	0.55	0.93	0.76	0.65	0.28	0.43	0.62

As in Table 1, the yields in Table 2 indicate the diseased plants yielded much less than those classed as healthy.

Weight per 1000 Kernels

Two-hundred-kernel lots of each sample were counted out and the 1000-kernel weights calculated. These are shown in Table 3.

TABLE 3.—WEIGHT IN GRAMS PER 1000 KERNELS

Class	Field number								Class means
	1	2	3	4	5	6	7	8	
Healthy	27.0	31.1	28.6	23.6	19.7	33.3	26.3	26.9	27.1
Diseased	18.3	23.3	24.4	17.9	16.3	20.0	20.5	15.4	19.5

Table 3 indicates a substantial reduction in filling of the grain in the diseased as compared with the healthy patches. The reduction in the means is about 28%, whereas the reduction in the yield of grain per plant, Table 2, is about 48%. It is evident, therefore, that in addition to a reduction in weight per kernel there is also a reduction in number of kernels per plant, in the diseased areas as compared with the healthy areas. The onset of the disease must, therefore, have been prior to seed setting, and its effects continued during the filling of the seed. This is borne out by data taken on the number of heads per plant in sample No. 5. The 103

healthy plants averaged 3.94 heads per plant, while the 104 diseased plants averaged 3.06 heads. Figure 1 indicates that disease was present even earlier; i.e., during the period of elongation of the culms, since a reduction in height is pronounced.

Root-rot Data

The plants were classified on the basis of internal crown lesions into 11 classes, following the method of Broadfoot (1). Each of these classes was then subdivided into 4 classes on the degree of external lesioning of the subcrown internode, Russell and Sallans (2). In this way, the plants were classified in 2-way tables for each sample. An example is shown in Table 4. To obtain a single estimate of disease based on both methods, the plants in the 2-way tables were divided into 4 parts, as indicated in Table 4 by the double lines.

TABLE 4.—TWO-WAY CLASSIFICATION OF PLANTS IN THE SAMPLE FROM THE DISEASED AREAS OF FIELD NO. 2

Subcrown internode lesion classes	Crown lesion classes											Totals
	0	1	2	3	4	5	6	7	8	9	10	
0	0	2	2	4	6	3	5	0	1	1	0	24
Slight	0	0	3	9	15	12	11	8	0	1	1	60
Moderate	0	0	1	7	7	8	10	7	6	1	0	47
Severe	0	0	1	3	3	10	6	9	1	5	0	38
Totals	0	2	7	23	31	33	32	24	8	8	1	169

Table 5 shows the results on totalling the numbers of plants in each quadrant of Table 4.

TABLE 5.—A TWO-WAY TABLE OF 4 CLASSES FORMED FROM TABLE 4

Subcrown internode lesion classes	Crown lesion classes	
	0–5	6–10
0—slight	56	28
Moderate—severe	40	45

To obtain a single value representing the amount of disease present, it was necessary to assign values to each of the 4 classes. These were related to yields by classifying 144 plants and obtaining the average yield per plant for each of the 4 classes. These are shown in Table 6 in percentages of the class with least disease. The figures in brackets are the factors derived from the yield data for use in estimating the disease rating.

TABLE 6.—AVERAGE PLANT YIELDS, EXPRESSED AS PERCENTAGES OF THE LEAST DISEASED CLASS, FOR 144 PLANTS IN 4 LESION CLASSES

Subcrown internode lesion classes	Crown lesion classes	
	0–5	6–10
0—slight	100 (0)*	72 (3)
Moderate—severe	69 (3)	60 (4)

* The numbers in brackets are the factors derived on the basis of the yield data for calculation of disease ratings.

The disease rating for the data of Table 5, for example, is calculated as follows: $\frac{(28 \times 3) + (40 \times 3) + (45 \times 4)}{4} \times \frac{100}{169} = 57.$

While it may be somewhat troublesome to cut into crowns of plants to determine the extent of invasion by root-rot fungi, it seems worthwhile. The data in Table 6 show both internal crown and external subcrown internode lesions to be approximately equally associated with reductions in yield. Moreover, the 2 types of lesion are not correlated to any considerable degree as, for example, in Table 4. Hence it seems that a truer estimate of infection can be obtained by taking into account both subcrown internode and internal crown lesions.

Following this method, the root-rot ratings in Table 7 were obtained.

TABLE 7.—DISEASE RATINGS INDICATING THE AMOUNT OF COMMON ROOT ROT IN THE VARIOUS SAMPLES

Class	Field number								Class means
	1	2	3	4	5	6	7	8	
Healthy	24	25	7	29	32	28	35	19	25
Diseased	54	57	52	70	60	80	61	64	62

In Table 7 there is evident a consistently higher common root-rot, disease rating for the diseased areas than for the healthy. From this table it becomes evident that the so-called healthy areas are also affected by common root rot, though to a much lesser degree than the areas designated as diseased.

To determine the extent of the common root-rot fungi present in the diseased tissues of the crowns and subcrown internodes, pieces of these tissues were incubated in small moist chambers on moist blotting paper. This test is designed to bring up *Helminthosporium sativum* particularly as it is usually the principal fungus causing common root rot in wheat in Saskatchewan. The data of Table 8 show the percentages of pieces out of 20 which produced *H. sativum*.

TABLE 8.—PERCENTAGES OF CROWN AND SUBCROWN INTERNODES WHICH YIELDED *Helminthosporium sativum*

Class	Field number								Class means
	1	2	3	4	5	6	7	8	
Healthy	100	70	55	95	60	95	90	70	79
Diseased	80	55	85	90	65	95	85	75	79

Over the 8 fields in the study, about 80% of the lesioned tissue yielded *H. sativum*. This was true for both healthy and diseased areas. Various miscellaneous fungi appeared in most cases where *H. sativum* did not. Some at least of these may have been pathogenic species of *Fusarium*.

THE INFLUENCE OF WEATHER

Weather data were obtained from the fortnightly crop reports issued by the Dominion and Saskatchewan Departments of Agriculture. Six stations; namely, Pennant, Aneroid, Cadillac, Val Marie, Shaunavon, and Instow are located in the general area throughout which the outbreak of common root rot occurred. As there was a fair degree of consistency in the data, they were averaged for the 6 stations and are presented in Figure 3 in graphic form. The rainfall is given in weekly totals and air temperatures as weekly means. The long time mean air temperatures averaged for the 6 stations are also shown.

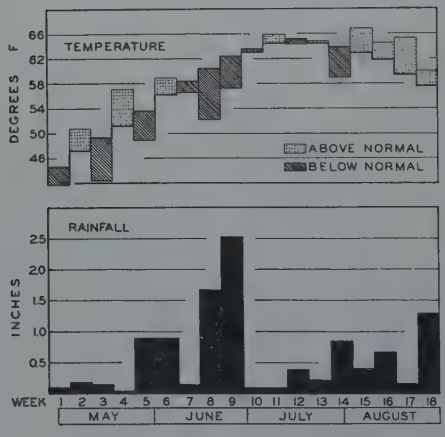

FIGURE 3. Air temperatures and rainfall, average of six stations, in 1942 in the area of severe common root rot. Rainfall is shown for weekly periods. The weekly mean air temperatures are shown as deviations from the long time averages.

Following a very dry period of $3\frac{1}{2}$ weeks in May, ample rain fell up to the end of June. The rainy period was accompanied by lower than average air temperatures. In consequence, after a rather slow start, the crops tended to be heavy and late by the end of June. The first 4 weeks of July were very dry; and, toward the end of this period, the heavy growth of crops had drawn heavily on soil moisture reserves, so that further rainfall was needed for filling. The crop reports indicate that heading was late. About 25% of the wheat was headed by July 14 and 95% by July 28. Following the midseason dry spell, normal rainfall occurred in August accompanied by unusually high air temperatures, which undoubtedly raised soil temperatures about the crowns of the crop.

The influence of weather on the course of the disease is only partially understood. However, it is probable that the plants, suffering somewhat

from drought in mid-season, were easily invaded by the common root-rot fungi, present in the soil. The higher than normal soil temperatures of August would be unfavourable to the wheat plant but were optimum for the development of the invading fungi. The infection, therefore, became well established in the tissues of the crown and sub-crown internodes, and interfered with normal conduction of water and nutrients from the soil to the leaves. Similarly the transfer of photosynthetic products from leaves and stems to the growing root systems would be hindered.

These effects would be indicated in lowered yields, thin kernels, and, if sufficiently pronounced, in premature drying up of the plants.

DISCUSSION

From this study, it appears that the conspicuous disease affecting considerable areas in many wheat fields in the Ponteix-Cadillac district was an aggravated form of common root rot, caused principally by *Helminthosporium sativum*, and also possibly certain other fungi, such as *Fusarium* spp.

While the root-rot fungi were the primary agents in causing the condition, other factors were undoubtedly contributory to the intensity of the attack. After a good start in May and early June, the crops suffered from a period of drought. This period was then followed by ample moisture throughout the remainder of the growing season. It seems probable that during the unfavourable period of drought the plants may have been retarded in growth, and in a weakened condition been more subject to attack by the root-rot fungi. This attack when localized in the subcrown internode would reduce the efficiency of the primary root system, and when localized in the crown would partially cut off the crown root system. Thus supplies of water and minerals from the soil would be partially prevented from entering the plant. A reduced rate of growth would result, with a consequent stunting of the plants. The transmission of water through the injured crown tissues may have been reduced to the extent that premature drying out of the leaves and stems took place. This early killing of the diseased plants would account for the very noticeable degree of weathering of the straw and chaff ahead of the normally ripened plants.

The fact that the disease occurred in its worst form in distinct patches in the field is evidently due to soil variations. As a result of these variations, the moisture available to the plants during a period of drought may have been depleted more rapidly in some areas than in others. Similarly the amount of root-rot fungi in the soil may have varied considerably from one place to another.

No investigation was made as to the reasons for the soil variations. Wind erosion of some areas may have been a factor.

A fact of much importance is that even the areas designated as healthy or normal in appearance were actually diseased though to a lesser degree than the poor areas. Tables 4 and 5 indicate that *Helminthosporium sativum* caused considerable common root rot in the healthy areas. That these areas suffered a reduction in yield seems probable. When the yields of Table 1 are plotted against the respective disease ratings of Table 7 as

in Figure 4, the relation between disease rating and yields becomes clear. As disease ratings increase, yields decrease. This is true for each of the 6 fields as well as for the means of the 6 fields. When the line joining the means of the diseased and the means of the healthy areas is extended (dotted lines in Figure 4) an estimate of the probable yield in the absence of the disease can be made. Thus from Figure 4 it would seem that the average yields in the 6 fields might have been 40 bushels per acre instead of the 31 bushels in the so-called healthy areas and the 16 bushels in the diseased patches. To make this estimate, it must be assumed that there is a straight line relation between yield and common root-rot disease ratings. That such is the case has been indicated in work at this laboratory.

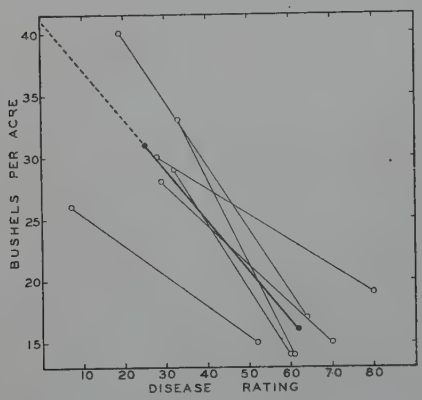

FIGURE 4. The relation between disease rating and yield in paired samples from six fields, light lines represent individual fields and the heavy line the average for the six fields. The broken line is a continuation of the average line, on the assumption that there is a straight line relationship between disease rating and yield, to indicate the possible yield in the absence of the disease.

Since rough estimates of the percentages of the fields in the diseased patches were made, it is possible—making use of the data in Table 1—to estimate the yields that would actually be obtained. Table 9 shows these estimates, together with reductions from yields of the healthy areas.

TABLE 9.—PERCENTAGES OF FIELDS OCCURRING IN DISEASED PATCHES AND ESTIMATES OF YIELDS FOR THE WHOLE FIELD

	Field number						Means
	3	4	5	6	7	8	
Percentage of field in patches	15	45	60	90	45	75	55
Yields of healthy areas, bushels per acre	26	28	29	30	33	40	31
Estimated yields for the field, bushels per acre	24	22	20	20	25	23	22
Reduction due to disease in patches, bushels per acre	2	6	9	10	8	17	9

From Table 9 it appears that the losses due to the disease, using the healthy appearing areas as standards of comparison, ranged from 2 to 17 bushels per acre. On a percentage basis, the losses ranged from 8 to 42% of what the yield might have been if the fields were uniformly like the healthy appearing areas. These estimates do not take into account losses caused by the disease in the "healthy" areas. Neither do they consider losses in grade, or losses in harvesting due to breaking down of the plants.

While the losses in wheat yields for the province as a whole would be slight as a result of this outbreak of root rot, individual farmers suffered very substantial losses, and probably whole municipalities were considerably affected.

While the common root-rot condition found at Ponteix, Cadillac, and neighbouring areas this year was sufficiently prominent to attract attention and cause concern, the disease does not usually become so manifest in Saskatchewan. However, the disease is present every year in nearly all cereal crops and frequently does injure the crops very materially.

Control measures for common root rot are not well developed. In general, any practice which tends to promote quick, vigorous growth of the plants will help them to recover from the disease. The use of oats or flax after badly affected wheat may have considerable value.

SUMMARY

The occurrence of an unusually severe outbreak of common root rot of wheat in southwestern Saskatchewan is recorded. Paired square-yard samples from diseased and nearby healthy-appearing areas from several fields were studied. The prematurely ripened, stunted and discoloured plants from the diseased areas yielded about half as much grain as the healthy areas. The weight per thousand kernels was reduced about 28% by the disease. Common root-rot ratings were much higher for the diseased areas than for the healthy-appearing areas. *Helminthosporium sativum* P.K. and B. was quite consistently isolated from diseased tissues. Possible relations of weather to the severe outbreak of the disease are discussed.

ACKNOWLEDGMENTS

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METHODS OF SELFING AND CROSSING CRESTED WHEAT GRASS, *AGROPYRON CRISTATUM* (L.) BEAUV.[1]

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Crested wheat grass is particularly adapted to the open plains region of Western Canada because of its hardiness and drought resistance. Improvement of this grass at the Dominion Forage Crops Laboratory, Saskatoon, Sask., has not extended beyond the selection by Kirk (11) of the finer, shorter growing, Fairway type from the common or forage type. Extreme self-sterility and a lack of suitable hybridization methods are factors greatly retarding the development of superior strains.

Large cotton cages have been used for several years in selfing crested wheat grass but the high cost of materials has prohibited an extensive selfing programme. This paper reports investigations made to find the suitability of Kraft and glassine bags for selfing purposes. A method of bulk emasculation by hot water treatments is also described, together with methods of bulk pollination which may be used in conjunction with bulk emasculation.

LITERATURE REVIEW

Descriptions of the Fairway and common types of crested wheat grass were given by Kirk (11) and Hay (6). Cytological investigations were made by Peto (16), Myers and Hill (15), and Murphy (14). The 2n chromosome number for the common type was found to be 28, whereas that of the Fairway type was found to be 14. Occasional aneuploidy was observed in the common type.

Although considerable literature is now available regarding selfing and pollination methods for the grasses, that pertaining directly to crested wheat grass is limited. Murphy (14) used parchment bags, 4 inches by 8 inches in size, for selfing purposes. Nearly all plants studied proved highly unfruitful with this method of isolation. Under space-isolation, some plants gave considerably more seed than when isolated with parchment bags. Certain plants were found to be cross-incompatible when space-isolated in pairs.

Several modifications in the method of hand pollination described by Hayes and Immer (7) for wheat, oats, and barley have been reported by cereal and forage crop breeders. Jenkins (8), in crosses of several grass species, applied pollen with a soft brush, the pollen being collected from selfing bags on the male parent. Florell (4), Johnson and McLennan (10), Engelbert (3), and Pope (17), working with wheat and various grass species, made very successful pollinations by using dry, dehisced pollen rather than ripe anthers.

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Emasculation by means of hot water treatments was first reported by Stephens and Quinby (19) in sorghum crosses. They found that a differential tolerance of flower parts to hot water allowed anthers to be killed without serious damage to pistillate organs. Li, Meng, and Liu (13) were unsuccessful in their first attempt to emasculate millet *(Setaria italica)* by this method. Jodon (9), working with rice, and Domingo (2), working with smooth brome grass, obtained satisfactory emasculation by the use of hot water treatments.

Partial self-fertility is a factor generally preventing the hybridization of grasses without previous emasculation. Frandsen (5) found that isolation in cocksfoot gave about 6% seed setting, whereas cross-pollination obtained by enclosing the inflorescences of different plants together under parchment and linen covers gave about 65% seed set. Sylven (20), working with timothy and cocksfoot, found cross-pollination, effected by dusting foreign pollen over enclosed inflorescences, gave inconsistent increases in seed setting over that from isolation without cross-pollination. Stapledon (18) concluded that cross-pollination in cocksfoot was 6 to 10 times as effective as self-pollination. Stapledon obtained intercrossing by placing several plants together under space-isolation and isolation under cages and in greenhouses. In extensive studies of self- and cross-fertility in the grasses, Beddows (1) found almost all species showing a certain degree of self-fertility. In only 5 out of 61 species reported did the ratio of "free" to "enclosed" seed exceed 100.

Domingo compared the seed setting of smooth brome grass following selfing with that following various methods of bulk cross-pollination. Most satisfactory cross-pollination was obtained by (1) placing male and female inflorescences together under the same isolation bags, and (2) transferring pollen collected in an isolation bag on the male inflorescences to female inflorescences previously isolated in pollen bags. Single transfers of pollen immediately after flowering, in the late afternoon, were found to give better seed setting than single pollination delayed until the next morning, or repeated pollination given at various times throughout the day. Domingo, however, did not find the ratio of crossed to self seed sufficiently high to eliminate the necessity of emasculation.

EXPERIMENTAL METHODS AND RESULTS

Methods of Selfing

From 1939 to 1941, a test of selfing was conducted in which the seed setting of crested wheat grass within cotton cages was compared with that under Kraft and glassine paper bags. The cotton cages used were 3 feet square, 6 feet high, and similar to those described by Kirk (12) for selfing brome grass and slender wheat grass. A heavy cotton material, 2.85 yard, 48 × 48 was used in the making of these cages.[1] The Kraft and glassine paper bags were approximately 10 inches by 4 inches in size, and were supported by bamboo canes. Isolation with these 3 methods was carried out in duplicate on clones of each of 6 crested wheat grass plants of the Fairway type. Five of these plants had appeared comparatively self-fertile and one comparatively self-sterile on the basis of selfing with

[1] Cloth runs 2.85 yards per pound with a thread count of 48 by 48 per square inch.

large cotton cages in 1938. The treatments were applied at random to the clones of each strain, and a different randomization of treatments was used each year.

The summarized data of this test are shown in Table 1. In this and succeeding studies the success of seed setting has been recorded as the percentage of florets forming seeds. In general, 5 to 15 heads, involving from 500 to 2000 florets, were used in each determination of seed setting. The number of florets on each head was found by multiplying the number of spikelets in the head by the average number of seeds per spikelet, as determined from 3 representative spikelets throughout the length of the head. Values shown in Table 1 are average values of duplicate treatments. No data were obtained with respect to seed-setting under open-pollination in 1939, and in 1941 considerable shattering of open-pollinated heads occurred before harvesting.

TABLE 1.—THE PERCENTAGE SEED SETTING OF 6 FAIRWAY CRESTED WHEAT GRASS STRAINS FOR 3 METHODS OF SELFING AND FOR OPEN-POLLINATION, 1939–1941

Treatment	Year	Per cent seed setting for strains†						Average for year
		308–61	308–62	308–63	308–64	308–65	308–66	
		%	%	%	%	%	%	%
Glassine bag	1939	0.00	0.00	0.00	0.00	0.06	—	—
	1940	0.30	0.00	0.07	0.00	0.10	0.00	0.08
	1941	0.05	0.05	0.03	0.02	0.07	0.10	0.05
Kraft paper bag	1939	0.00	0.00	0.00	0.00	0.00	—	—
	1940	0.02	0.05	0.02	0.01	0.06	0.00	0.03
	1941	0.01	0.05	0.02	0.08	0.02	0.00	0.03
Cotton cage	1939	0.23	0.40	0.17	0.24	0.38	0.08	0.25
	1940	1.26	9.33	5.09	2.56	7.32	0.20	4.29
	1941	0.84	4.04	1.41	9.84	2.45	1.44	3.34
Open-pollination	1939	—	—	—	—	—	—	—
	1940	32.56	69.44	53.38	86.88	49.17	57.04	58.08
	1941*	12.92	14.17	10.90	45.50	10.30	10.52	17.38

* Considerable shattering before harvesting.

† In 1938 the strains in order from 308–61 set the following amounts of seed under cotton cages: 15, 32, 20, 20, 20, and 0.1 grams.

It is quite apparent that selfing crested wheat grass by means of small Kraft and glassine paper bags is unsatisfactory. Practically no seed was set under these isolation treatments in any plant for any year. Under cotton cages the amount of seed produced was low, but usually adequate for progeny testing. With cotton cages, there was marked variation in the reaction of various strains during the same year. It was observed that this variation also occurred between duplicate treatments on clones of any one strain. The difference in seed setting following selfing with paper bags and with cotton cages cannot be explained. It would appear that seed setting conditions were very unfavourable under the paper bags, or that the cotton cages were not pollen proof and allowed some cross-pollination.

In 1942, an additional study of selfing was made to determine the interplant variation with regard to self-fertility, and to find if increased seed setting would result from delayed selfing. A row of 20 spaced plants of unselected Fairway material and a row of 20 spaced plants of unselected common material were used in this test. One-quarter-pound Kraft paper bags were applied at various dates previous to flowering to each plant. The small size of selfing bag obviated the necessity of using supports. Despite unusually heavy rains during flowering, only slight weather damage resulted. In Table 2, the seed setting of the 20 Fairway plants is recorded. The 20 plants of the common type reacted similar to the Fairway plants, and only a summary of their behaviour is given in Table 2. Flowering commenced in the common type several days in advance of flowering in the Fairway type, thus the dates of selfing for the 2 strains do not correspond. On some plants selfing bags were applied after flowering had commenced but in these cases only late heads showing no flowering were used.

TABLE 2.—THE SEED SETTING OF CRESTED WHEAT GRASS FOLLOWING SELFING WITH KRAFT PAPER BAGS AT VARIOUS DATES PREVIOUS TO FLOWERING, 1942

Strain	Plant No.	Date of first flowering	Per cent seed setting when selfed on:						Average*
			June 18	June 24	June 27	June 29	July 2	July 5	
			%	%	%	%	%	%	
Fairway	98–1	July 1	0.07	0.00	0.00	0.19	0.00	0.00	0.05
	98–2	July 2	0.00	0.00	0.00	0.11	0.00	0.00	0.02
	98–3	July 5	0.00	0.00	0.00	0.00	0.09	0.12	0.02
	98–4	July 5	0.06	0.00	0.69	0.00	0.00	0.00	0.15
	98–5	July 5	0.00	0.00	0.00	0.43	0.00	0.00	0.09
	98–6	July 5	0.05	0.00	0.26	0.00	0.00	0.70	0.06
	98–7	July 5	0.40	0.00	0.35	0.08	0.09	—	0.18
	98–8	July 5	0.08	0.08	0.44	0.22	0.24	0.35	0.21
	98–9	July 5	0.75	0.00	0.00	0.25	0.00	0.41	0.20
	98–10	July 5	0.00	0.06	0.00	0.00	0.00	0.00	0.01
	98–11	July 5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	98–12	July 2	0.20	0.00	0.17	0.14	0.21	—	0.14
	98–13	July 4	1.22	3.56	3.33	2.62	1.77	—	2.50
	98–14	July 5	0.18	0.00	0.15	0.07	0.35	0.00	0.15
	98–15	July 1	0.00	0.10	0.14	0.00	0.20	0.00	0.09
	98–16	July 7	0.18	0.00	0.11	0.00	0.11	—	0.08
	98–17	July 5	0.00	0.08	0.00	0.00	0.00	—	0.02
	98–18	July 5	0.00	0.00	0.00	0.00	0.00	—	0.00
	98–20	July 5	0.00	0.00	0.00	0.00	0.06	0.00	0.01
	98–21	July 5	0.00	0.00	0.07	0.00	0.09	0.00	0.03
Average, 20 plants			0.16	0.19	0.28	0.21	0.16	—	0.20
Common Average, 20 plants			0.11	0.41	0.23	0.65	—	—	0.32

* For Fairway, the average does not include data for July 5.
For Common, the average includes additional data of June 22 when the 20 plant average showed 0.18% seed setting.

Considering the first 5 dates of bagging, the Fairway material shows an average seed set of 0.20% on selfing. Two plants were completely self-sterile, and 13 plants showed less than 0.10% seed setting. One plant, 98–13, was outstanding in regard to self-fertility, as 2.50% of the florets

set seed. As little difference in seed setting took place on the different dates, it appears as if delayed bagging is of no advantage in obtaining selfed seed. The plants of the common strain showed greater self-fertility than the Fairway strain, especially for selfings made on June 24 and June 29. The increased self-fertility on these 2 dates was due largely to increased seed setting on a few of the more self-fertile plants. Three common plants were completely self-sterile and 10 plants showed less than 0.10% seed setting.

Hand Emasculation and Pollination

Controlled crosses with hand emasculation and pollination were first attempted in 1938, when several crosses were made between the Fairway and common types, and within the Fairway type. The crossing technique used was essentially that described by Hayes and Immer (7) for wheat, oats, and barley. Pollinations were made 3 to 4 days after emasculation, during the late afternoon when flowering was general over the plants concerned. Of 397 florets crossed in 1938, only 1 set seed. Crosses were again attempted between the Fairway and common types, and between Fairway and a dwarf Fairway type in 1938, 1940, and 1941, but not a single seed was obtained. Failure was attributed primarily to severe withering of florets following emasculation, but cross-incompatibilities of the different plant types could also have been a factor.

In 1942, several crosses were attempted within the Fairway and common types, and between the 2 types. Emasculations were made in triplicate with 2 of the emasculated heads being covered with glassine

TABLE 3.—HAND EMASCULATION AND POLLINATION OF CRESTED WHEAT GRASS, 1942

Cross		Seed setting following emasculation and:					
		No pollination		Open-pollination		Cross-pollination	
Row Plt.	Row Plt.	No. florets	No. seeds	No. florets	No. seeds	No. florets	No. seeds
				Fairway × Fairway			
62–32	54–12	55	0	63	11	61	5
54–12	62–32	46	0	25	9	20	2
103–6	106–5	18	0	17	0	18	2
107–8	106–5	18	0	14	0	13	3
	Total	137	0	119	20	112	12
				Common × Common			
23–11	22–12	40	0	50	12	24	9
				Fairway × Common			
65–15	22–12	20	0	—	—	16	0
				Common × Fairway			
50–2	62–32	20	0	—	—	20	0
16–16	65–15	18	0	—	—	18	0
	Total	38	0	—	—	38	0

bags and 1 being left for open-pollination. One of the 2 covered heads was later cross-pollinated and 1 was left as a check on emasculation. Instead of transferring ripe anthers in making pollinations, heads of the male parent were placed inside the selfing bag of the female parent, and the whole tapped vigorously. The male head was then withdrawn from the selfing bag and discarded. The selfing bag on the female parent was then tied tightly about the female elements. The results of the 1942 crossings are indicated in Table 3.

Since enclosed heads left unpollinated set no seed, the emasculation technique may be described as fully efficient. The low seed set of open-pollinated heads indicates, however, that this method of emasculation is very harmful to future seed setting. Controlled pollinations resulted in fair seed setting except in the Fairway × common, and reciprocal crosses. In 1942, as contrasted with previous years, no severe wilting of floral parts took place following emasculation. Ample soil moisture and humid weather conditions at flowering time seemed to favour the recovery of injured flower parts.

Hot Water Emasculation

Considering the difficulties attending hand emasculation in crested wheat grass, investigations were made of bulk emasculation methods. Hot water emasculation trials were carried out in 1939 and 1940 using various temperatures for different durations. Six plants, found to be comparatively self-fertile in cotton cages, were cloned and the clones established out-of-doors in 8-inch pots. A few days previous to flowering, the potted clones were taken to the greenhouse where facilities were available for regulating temperatures. The various treatments were given to the clones of each strain. Only heads approaching flowering were used, and these were trimmed to florets uniform as to stage of anther development. The efficiency of emasculation was tested by allowing each treated clone to flower under space-isolation. A second set of treated clones was placed under open-pollination to find the effect of emasculation treatment on pistillate organs. Untreated check clones were also grown under space-isolation and open-pollination. The 1939 results were incomplete and will be referred to only where they substantiate the 1940 results. The emasculation treatments given in 1940, and the seed setting of treated and check clones after flowering under open-pollination and space-isolation, are shown in Table 4.

The lack of seed from treated clones when placed under space-isolation indicates that all emasculation treatments were effective. Under open-pollination, however, there was considerable variation in seed setting. The shorter treatments at each of the 3 temperatures gave better seed setting than the longer treatments. The 48° C. treatment for 1 minute appears especially desirable for the emasculation of crested wheat grass. In 1939, the 48° C. for 1 minute was also the most successful method of emasculation. Clones treated in this manner gave no seed under space-isolation and 6.6% seed setting under open-pollination. Treatments of longer duration at temperatures of 42° C. and 44° C. were also used in 1939, but were found to give imperfect emasculation and to result in considerable damage to pistillate organs. The seed setting of check clones under open-pollination

TABLE 4.—THE PERCENTAGE SEED SETTING OF CRESTED WHEAT GRASS FOLLOWING BULK EMASCULATION BY HOT WATER, 1940

Strain No.	Per cent seed setting following emasculation						No. treatment
	46° C.		48° C.		50° C.		
	3 min.	6 min.	1 min.	2 min.	½ min.	1 min.	
	Open-pollination						
114–3	8.4	0.0	25.5	0.0	3.8	0.0	5.5*
115–21	7.9	0.7	11.4	0.0	6.5	0.4	3.2*
118–13	0.0	0.0	0.0	0.0	0.0	0.0	—
120–20	0.0	0.0	4.3	0.6	0.6	0.0	1.8*
130–9	—	0.7	25.7	6.1	14.8	4.2	31.2
130–2	0.0	0.0	4.4	0.0	0.2	0.0	—
Average (weighted)	3.8	0.3	13.3	0.1	4.8	1.0	31.2
	Space-isolation						
114–3	—	0.0	—	0.0	0.2	0.0	—
115–21	0.0	0.0	0.0	0.0	—	0.0	0.0
118–13	0.0	0.0	0.0	0.0	0.0	—	—
120–20	0.0	0.0	0.0	0.0	0.0	0.0	0.5
130–9	0.0	0.0	0.0	0.0	0.0	0.0	—
130–2	0.0	0.0	0.0	0.0	—	0.0	0.7
Average (weighted)	0.0	0.0	0.0	0.0	0.1	0.0	0.4

* In greenhouse. (Not included in average).

is given for 1 strain, 130–9, in 1940. Three check clones were accidentally left in the greenhouse during flowering. Check clones of 130–9 and 130–2 set seed satisfactorily under open-pollination in 1939. Check clones in 1940 set little seed when space-isolated. It would appear that emasculation of these plants in crossing work would scarcely be necessary in view of their high degree of self-sterility.

Bulk-pollination Without Emasculation

A large number of crosses, using bulk methods of pollination on unemasculated heads, were carried out in 1942. The rows of unselected Fairway and common materials described in the methods of selfing test in 1942 were also used in this test. Adjacent plants within each row were intercrossed (1) by means of a bag transfer of pollen and (2) by means of connecting glassine sleeves. In the bag transfer method of crossing, 2 one-quarter-pound Kraft paper bags were applied to each plant 1 to 2 days previous to flowering. Bags on adjacent plants were then interchanged during the late afternoon of 3 days when these plants were flowering. Each time pollen bags were transferred they were tapped sharply to distribute transferred pollen over enclosed inflorescences.

In the glassine sleeve method of crossing, several heads of adjacent plants were entered through opposite ends of a glassine sleeve. This sleeve was formed by cutting open the closed end of a glassine bag, size 3 × 7 inches. The enclosed heads were held adjacent to one another within the sleeve by tying each end of the sleeve tightly around the culms entering the sleeve. No further attention was given to these bags other than to tap them sharply on 3 days when flowering occurred.

The results of these 2 methods of bulk-pollination are indicated for the 20 Fairway plants in Table 5. The success of crossing is indicated for each plant according to which adjacent plant was used as the pollen source. As the reaction of the common material was similar to that of the Fairway, only the average values obtained from 16 plants with complete data are shown in Table 5. The seed setting of each plant under open-pollination was obtained from a single determination. Self-fertility values are those shown in Table 2 for the self-fertility study.

TABLE 5.—THE SEED SET OF CRESTED WHEAT GRASS FOR TWO METHODS OF BULK CROSS-POLLINATION AND FOR SELF- AND OPEN-POLLINATION, 1942

♀ Plant No.	Per cent florets setting seed following: Bulk cross-pollination							Selfing	Open-pollination
	A. Glassine sleeve			B. Pollen transfer			Average A and B		
	♂ a*	♂ b†	Ave.	♂ a	♂ b	Ave.			
					Fairway				
98–1	—	1.03	—	—	5.81	—	—	0.05	16.53
98–2	0.45	3.31	1.88	7.74	0.15	3.94	2.91	0.02	35.42
98–3	12.64	9.34	10.99	11.91	6.24	9.08	10.03	0.02	45.56
98–4	12.21	0.40	6.30	4.12	5.62	4.87	5.59	0.15	34.38
98–5	4.31	3.48	3.90	14.38	1.22	7.80	5.85	0.09	78.48
98–6	17.31	0.43	8.87	13.09	25.99	19.54	14.20	0.06	56.34
98–7	0.42	18.25	9.34	3.47	0.70	2.08	5.71	0.18	51.95
98–8	23.51	3.82	13.66	14.72	9.58	12.15	12.90	0.21	61.25
98–9	9.32	2.88	6.10	11.34	3.26	7.30	6.70	0.20	46.98
98–10	1.09	0.00	0.55	2.71	26.17	14.44	7.50	0.01	46.13
98–11	0.00	0.00	0.00	0.00	0.15	0.08	0.04	0.00	37.35
98–12	9.95	7.81	8.88	13.62	11.02	12.32	10.60	0.14	53.03
98–13	21.83	20.20	21.02	16.60	28.57	22.59	21.80	2.50	—
98–14	7.23	0.38	3.80	3.57	3.59	3.58	3.69	0.15	85.42
98–15	—	22.99	—	19.97	1.38	10.68	—	0.09	58.96
98–16	0.22	0.00	0.11	0.61	1.14	0.88	0.50	0.08	37.60
98–17	—	0.00	—	0.00	0.00	0.00	—	0.02	41.67
98–18	0.00	—	—	2.95	12.10	7.52	—	0.00	56.69
98–20	—	9.70	—	2.56	12.46	7.51	—	0.01	27.72
98–21	4.84	—	—	22.54	—	—	—	0.03	29.17
Average 13 plants			5.72	—	—	7.54	6.63	0.10	51.53
% of open-pollination			11.10	—	—	14.63	12.87	0.19	100
					Common				
Average 16 plants			14.60	—	—	16.54	15.57	0.38	40.16
% of open-pollination			36.35	—	—	41.18	38.77	0.95	100

* Adjacent plant standing lower in the row; e.g., For plant 98-2 as ♀, ♂ a = plant 98-1.
† Adjacent plant standing higher in the row; e.g., For plant 98-2 as ♀, ♂ b = plant 98-3.

Although there is much variation among plants in the success of cross-pollination, the amount of seed produced as compared with that from selfing is remarkable. In the Fairway material, 13 plants gave an average of 6.63% seed setting when crossed by the 2 methods. Upon selfing with Kraft paper bags only 0.10% seed setting was obtained. Similarly in the common type, controlled crossing gave 15.57% seed setting while selfing gave 0.38% seed setting. Pollinations by the bag transfer method were somewhat more successful than those by means of glassine sleeves.

Much of the failure in seed setting on crossing was due to plants flowering at different dates. As indicated in Table 2, Fairway plants began flowering from July 1 to July 7. Since plants remained in flower for about 6 days, poor pollinations were inevitable in certain cases. A slight amount of error in technique is apparent since the success of crossing by the 2 methods does not agree with respect to certain plants. The lower seed setting of controlled crosses was also found to be related to seed setting under open-pollination. For 29 plants with complete data, a significant correlation ($r = + .39$) was found between the percentage seed setting under open-pollination and average percentage seed setting when cross-pollinated.

In a more critical test of bulk-pollination by the bag transfer method, 18 plants of the Fairway and common types were intercrossed using various times and frequencies of bag transference. The plants used were grouped into 9 pairs so that the members of each pair began flowering on the same date. The members of each pair were crossed using 7 methods of pollen transference. The first method (a) consisted of making a single transfer of pollen between the hours of 4 and 7 p.m. on the second day of flowering. It was frequently observed that crested wheat plants would show sudden anthesis during the late afternoon of the second day of flowering, with a large proportion of the first and second florets of spikelets opening at this time. Before and after this date, flowering was less general. Single pollinations were also made on the third day of flowering, one in the forenoon (b) and one in the early afternoon (c). Repeated pollinations were made for 3 (d) and 5 (e) consecutive days of flowering. To investigate the possibilities of delayed pollination, single pollen transfers were made after anthesis on the fourth (f) and sixth (g) days of flowering. The success of these methods of pollination is given in Table 6.

Pollination between the Fairway and common types cannot be included in a comparison of crossing methods, since the 2 types apparently do not cross. As will be shown presently, the small amount of crossed seed which was formed seemed to be due to contamination from stray pollen. Crossing in the Fairway by (a), (d), and (e) methods gave variable, but in general, very favourable seed setting. Slight increases in seed setting took place when pollinations were repeated 5 times. Pollinations given on the morning and early afternoon of the third day were much less successful than pollinations made immediately after flowering. Pollinations made on the fourth and sixth days of flowering were also quite unsatisfactory. Considering the small amount of work involved, and the good seed setting obtained, single transfers of pollen made directly after peak anthesis appears a promising method of crossing crested wheat grass.

Table 6 also gives the seed setting of plants when selfed, and when left to open-pollinate. In one method of selfing, the pollination bag was removed and replaced directly on the second, third, and fourth days of flowering. This was done to find the extent of contamination from foreign pollen while making cross-pollinations by the bag transfer method. As in the previous test, the amount of seed from controlled crosses greatly exceeds that from selfing. In some plants, the average amount of seed formed by the 3 methods of cross-pollination is over 50% of that from open-pollination. The selfed series with the bags removed also set more seed

TABLE 6.—THE SEED SETTING OF CRESTED WHEAT GRASS FOLLOWING DIFFERENT METHODS OF BULK POLLEN TRANSFERENCE AS COMPARED TO THAT FOLLOWING SELFING AND OPEN-POLLINATION, 1942

Cross ♀ Row plt.	♂ Row plt.	Seed setting following: Cross-pollination by the pollen transfer method (a) 2nd day 4-7 p.m.	(b) 3rd day 9-10 a.m.	(c) 3rd day 2-3 p.m.	(d) 2nd-4th day 4-7 p.m.	(e) 2nd-6th day 4-7 p.m.	(f) 4th day 4-7 p.m.	(g) 6th day 4-7 p.m.	Ave. (a) (d) (e) methods	Selfing: Bag not removed	Selfing: Bag removed thrice	Open pollination
Common × Fairway												
22–12	65–15	0.00	—	0.00	0.00	0.00	0.00	0.00	0.00	—	0.00	40.39
56–13	65–22	0.00	0.00	0.00	0.17	0.28	0.00	0.00	0.15	0.00	0.00	29.10
16–16	103–19†	0.38	0.00	0.00	0.00	0.79	0.00	0.00	0.39	0.00	1.26	14.73
Average		0.13	—	0.00	0.06	0.36	0.00	0.00	0.18	—	0.42	28.07
Fairway × Common												
65–15	22–12	0.00	0.00	0.00	0.09	0.00	0.00	0.26	0.03	0.00	0.62	53.00
65–22	56–13	0.00	0.14	0.17	1.17	0.21	0.00	1.39	0.46	0.14	0.24	33.88
103–19†	16–16	0.82	0.29	0.09	0.90	0.40	1.76	0.62	0.71	1.27	0.46	73.02
Average		0.27	0.14	0.09	0.72	0.20	0.59	0.76	0.40	0.47	0.44	53.30
Fairway × Fairway												
58–36*	63–15	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	15.98
63–15	58–36*	1.75	0.44	0.00	1.54	0.91	0.22	0.41	1.40	0.00	0.10	39.45
64–45	106–1‡	14.42	9.06	12.54	18.84	39.17	10.60	0.10	24.14	0.34	0.00	35.77
106–1‡	64–45	11.55	2.67	0.43	15.27	6.88	0.20	0.22	11.23	0.45	0.09	46.85
65–3	65–9	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.05	0.00	0.17	37.92
65–9	65–3	0.47	0.59	0.11	5.83	2.26	1.64	2.78	2.85	0.00	0.00	47.24
103–6†	106–5‡	18.52	0.44	0.00	2.26	0.37	0.00	0.16	7.05	0.07	0.14	41.60
106–5‡	103–6†	26.87	0.94	0.00	12.00	4.47	1.21	0.00	14.45	0.10	0.21	74.78
107–8*	107–18*	7.38	1.43	0.82	11.90	0.87	10.13	1.63	6.72	1.32	6.82	61.89
107–18*	107–8*	18.80	0.68	0.59	16.06	39.86	3.23	5.18	24.91	0.14	2.33	67.33
54–18†	106–8‡	13.05	5.85	3.16	26.49	30.03	8.96	0.00	23.19	0.20	0.15	39.42
106–8‡	54–18†	4.73	0.11	3.14	2.91	11.39	9.19	—	6.34	0.07	0.10	27.98
Average		9.80	1.85	1.73	9.42	11.36	3.78	—	10.19	0.22	0.84	44.68

* Plant inbred one generation. † Plant inbred two generations. ‡ Plant inbred three generations.

than the series with bags left untouched. This indicates that considerable contamination from foreign pollen was occurring during cross-pollinations by the bag transfer method. As a precaution against such foreign pollen, plants within 4 feet of those being crossed were cut down previous to flowering. In addition, clean bags were placed over heads being pollinated, during the period of bag transference. It would appear from this study that further measures were necessary to exclude foreign pollen.

The marked variation in the success of Fairway crosses was unexpected, since plants were matched as to flowering dates. It is of interest to examine Table 6 to find if this failure might be due to inbreeding or to the incompatibility of related plants. Of the Fairway × Fairway crosses, plants in progeny rows 63 to 65 were not inbred, but the remaining rows represent material inbred from 1 to 3 generations. It is apparent from the last column of Table 6 that inbred plants set seed under open-pollination quite as well as those not inbred. Plant 58–36 was observed to have unusually red anthers. The low seed set of plant 63–15, with which it was crossed as male parent, and the low seed set of 58–36 under open-pollination indicate that this plant is largely male and female sterile. Two sister plants of row 65 showed poor seed setting when intercrossed, but formed considerable seed under open-pollination. Plan 107–8 similarly gave little seed when pollinated by the sister plant 107–18. Plant 106–8 gave little seed under controlled cross- or open-pollination.

Pollen Dispersal

A study of pollen dispersal with greased slides was made in 1942, and extended over a period of peak flowering from July 2 to July 7. Vertical and horizontal slide exposures were made in duplicate at 1.5-foot level in a large crested wheat grass test. Slides were exposed every 4 hours during the day from 6 a.m. to 6 p.m., and once during the 12-hour night period,

TABLE 7.—THE DISPERSAL OF CRESTED WHEAT GRASS POLLEN BY DAYS AND DAY PERIODS WITH CORRESPONDING WEATHER DATA, 1942

Exposure period	Total no. of grains per six microscope fields (diam. 2.25 m.m.)		Weather data			
	Horizontal	Vertical	Average temperature of	Average relative humidity m.p.h.	Average wind velocity	Total hours sunshine
			Days			
July 2	71	20	64.8	66.3	6.9	6.6
July 3	26	7	59.3	71.2	9.0	0.9
July 4	2824	1143	61.0	60.2	6.2	7.7
July 5	746	431	59.0	46.8	7.7	11.7
July 6	2870	800	66.3	53.3	6.6	12.7
July 7	232	164	69.0	63.3	7.1	9.2
			Day periods			
6 a.m. to 10 a.m.	66	21	60.0	67.3	8.3	9.8
10 a.m. to 2 p.m.	2141	668	69.0	43.5	8.1	17.2
2 p.m. to 6 p.m.	4516	1855	73.0	35.3	6.3	16.2
6 p.m. to 6 a.m.	46	21	59.2	71.7	7.0	5.6

6 p.m. to 6 a.m. Exposed slides were immediately examined under the microscope and pollen counts made for 6 low power fields (X60). Slide counts were then totalled according to the days of the study and according to day periods. Little foreign pollen was present on slides despite the close proximity of brome grass and sweet clover plots. The pollen counts obtained are shown in Table 7.

Previous to July 2, little flowering took place due to continued cloudy weather. There was little flowering on July 2, when it was warm and cloudy, and on July 3, when it was cool and cloudy. Much flowering took place during the afternoon of July 4 when the weather was hot, still, and cloudless. It appeared that a heavy dehiscence would take place on July 5 but the weather became cool and cloudy around 4 p.m. July 6 was warm and still, and flowering commenced before 2 p.m. July 7 was the hottest day of the study but little flowering took place. The failure of flowering on July 7 may have been due to high humidities on this day or to a completion of flowering in this field of crested wheat grass. These observations point to a concentrated type of anthesis in crested wheat grass with flowering taking place during the afternoons of warm days.

DISCUSSION

In crested wheat grass improvement, self-sterility is a factor frequently limiting the success of an inbreeding programme. Under Kraft and glassine paper bags, the amounts of selfed seed produced are negligible except for occasional plants. Although large cotton cages are definitely preferable to paper bags with regard to the amount of seed produced, the danger of contamination from cross pollen is not entirely eliminated. Unfortunately, no characters are yet available in crested wheat grass by which hybrid seeds may be detected. The remarkably good seed setting under paper bags following cross-pollination would indicate that the low seed set on selfing with these bags was due to true self-sterility, and not unfavourable conditions arising from bagging. This would lead one to suspect that the moderate degree of seed setting on selfing with large cotton cages was due to contamination from foreign pollen. It is quite apparent that a fuller investigation of methods of selfing for crested wheat grass is necessary.

In view of the marked self-sterility of crested wheat grass under paper bags, emasculation during crossing is usually unnecessary. Except for occasional self-fertile plants, the amount of seed produced on selfing in comparison with that from controlled crosses is very low. It is possible that contamination from stray pollen is more serious than that from self-fertility. Where it is desired to eliminate completely the possibility of selfing as in genetic studies, emasculation by hot water may be used.

The bag transfer method of pollination appears a more useful method of crossing than the method of isolating inflorescences of adjacent plants together, since plants desired for crossing will frequently be growing at some distance apart in nurseries. However, if plants are growing adjacent to one another, they may be crossed by the latter method with little work and little danger of contamination from outside pollen. Bulk pollinations

were attempted on a few plants by transferring flowering heads rather than dehisced pollen. Though this method gave good seed setting in a few cases, it appeared less favourable than the method of transferring pollen.

In crested wheat grass breeding nurseries, inbreeding has in many cases resulted in no serious reductions in plant vigour. However, no superior strains have been developed by inbreeding methods at this station. Several strains arising from single plant selections, following 1 year of inbreeding, have now been given critical tests and have not been found superior to Fairway in forage yields. A combination of inbred lines by bulk pollination methods is now contemplated.

SUMMARY

1. Selfing 6 crested wheat grass plants for 3 years with Kraft and glassine paper bags resulted in average seed setting values of less than 0.10%. Selfing clones of these plants with large cotton cages gave average values of 0.25 to 4.29%.

2. Hand pollinations of crested wheat were attended with considerable difficulty due to the small floret size and severe killing of floral parts following emasculation.

3. Satisfactory emasculation was obtained by the use of hot water. A treatment of 48° C., for 1 minute, was the most satisfactory method of emasculation on the basis of 2 years of study.

4. Selfing 13 plants of the Fairway type and 16 plants of the common type by small Kraft paper bags in 1942 gave average percentage seed setting values of 0.10, and 0.38, respectively. Bulk cross-pollination of these same plants by a bag transference of pollen gave corresponding percentage seed setting values of 7.54 and 16.54. Bulk cross-pollination with glassine sleeves gave percentage seed setting values of 5.72 and 14.60.

5. Pollinations made in the late afternoon, immediately after anthesis, gave better seed setting than pollinations delayed until the morning or early afternoon of the following day. Repeated pollinations appeared to have little advantage over single pollinations.

6. In 1942, a study of pollen dispersal in crested wheat grass showed flowering taking place over a short period of days. Practically all anthesis occurred on warm days between the hours of 2 and 6 p.m.

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EXPERIMENTS ON THE CONTROL OF THE CHRYSANTHEMUM MIDGE, *DIARTHRONOMYIA HYPOGAEA* F. LW.[1]

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In the past, the practices most commonly used for control of the chrysanthemum midge, *Diarthronomyia hypogaea* F. Lw. have been spraying with nicotine, or fumigating with either nicotine or cyanide. More recently certain proprietary sprays containing thiocyanates have been used effectively.

A brief note on the habits of the chrysanthemum midge is necessary for a proper understanding of the control measures. The larvae wander on the surface of the plant for a short time after hatching, then enter the leaf or stem tissue and form galls in which they live until the end of the pupal period. The adults begin to emerge at midnight, mate soon after, and at once start laying their eggs. By about 8 a.m. egg laying is largely completed and the flies begin to die. The great majority die before noon but a few individuals live for 24 to 36 hours, and a few eggs are sometimes laid during the day, especially when it is cloudy. The great majority of the eggs are laid on the tender growing tips of the plant. Reproduction goes on throughout the year in the greenhouse but appears to proceed at a much slower rate during June, July and August, probably owing to the unfavourable condition of the host. The duration of the life cycle from egg to adult varies from about 1 to 2 months or more, depending on the temperature and on condition of the host.

As spraying with nicotine has been directed chiefly against the adults and to a lesser extent against the eggs, it has been considered necessary to apply the spray late in the afternoon or evening so that it remains effective until the flies emerge at midnight. The applications have to be repeated at 2-day intervals for at least 6 weeks to clean up an infestation. When fumigants such as nicotine or cyanide are used, it is necessary to apply them daily at midnight for at least 6 weeks.

The experiments described in this paper were designed with the aim of finding an effective control programme which would entail fewer applications of the insecticide.

METHODS AND MATERIALS

As most of the insecticides used were proprietary products they will be referred to by letter. The manufacturers' specifications are as follows: *Rotenone spray A*—5% rotenone concentrate, made by dissolving a soft extract of derris root in acetone; *Rotenone spray B*—rotenone 1%, other derris resins 1.8%, technical mannitan monolaurate 97.2%; *Rotenone spray C*—rotenone 1%, other derris resins 2.3%, thymol 5.1%, mannitan monolaurate 11.2%, dibenzyl disulphide 1.5%, phenothioxin 1.5%, trichlorphenoxy-ethylchloride 20.5%, vegetable oils 55.9%, water and

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chlorinated hydrocarbons not more than 1%; *Thiocyanate spray A*—lauryl thiocyanate 40%, sulphated fatty matter 40%, inert 20%; *Thiocyanate spray B*—beta butoxy beta thiocyano either (normal butyl carbitol thiocyanate) 24%, phthalic anhydride glycerol alkyd resin 16.3%, pine oil 20.3%, petroleum oil 39.4%; *Fixed nicotine*—nicotine 14%, inert (micronized) 86%; *Nicotine sulphate*—40% nicotine; *"Free" nicotine*—40% nicotine; *Cocoanut oil soap*—40% anhydrous soap; *White oil*—A.P.I. gravity 37, visc. Say. at 100° F. 75–80, U.S.R. 92–96; *Lethane spreader*—proprietary non-soap, composition unknown.

The method of determining the population changes consisted of placing equal numbers of infested potted chrysanthemums in cotton gauze cages, each 3 feet high and with a bottom area of 2 feet by 3 feet. Living adults were counted, but not removed, daily between 8 and 9 a.m., over a period of 1 to 2 months or more for each experiment. It was noticed that some of the insecticides occasionally killed a few flies on the point of emergence so that the body was left attached to the pupal case which protruded from the gall. Adults thus killed were recorded and removed from the cage daily, while other dead adults were not counted or removed.

The sprays were applied with a DeVilbiss paint-type sprayer which delivered a fine mist. All sprays except those at 10 p.m. were applied to the plants on an open bench or in a cage with the door open, then at 10 p.m. all plants were returned to the cages and the doors closed.

Spray Schedules

The spray schedules are outlined in Table 1 and the results are given in Tables 2 to 6. Where two sprays, (*a*) and (*b*), are given for one cage, this indicates that the first treatment failed to give any appreciable control and so was replaced by the second treatment. In a few instances where it was considered advisable to continue taking emergence records for a longer period, a few plants or cuttings were removed to smaller cages in order to make the large cages available for other tests. These moves are indicated in the tables.

RESULTS

In evaluating the results it should be kept in mind that the comparisons of treatments are based on the short spray schedules of these tests and not on the potentialities of the insecticides when applied at short intervals over long periods as is the commercial practice of using some of the insecticides.

Tables 1 to 6, inclusive bring out a number of points of interest, the chief of which is that thiocyanate spray A, containing lauryl thiocyanate, was far more effective than any of the other materials tried. In experiment 1 it will be noted that no appreciable degree of control was obtained from the rotenone spray, the oil emulsion in bentonite, or the fixed nicotine. The fixed nicotine in oil emulsion (cage 2) apparently gave some control, although the emergence stayed at a fairly high weekly level throughout the test. However, this spray mixture left such a heavy disfiguring deposit on the foliage that it was entirely unsatisfactory. The thiocyanate spray gave the lowest total emergence and the greatest relative reduction in emergence for the last 5 weeks of the records.

TABLE 1.—CONTROL OF THE CHRYSANTHEMUM MIDGE ON POTTED CHRYSANTHEMUMS IN CAGES—EXPERIMENT 1—FIRST SPRAY APPLIED JUNE 4, 1940

Cage No.	Treatments	No. applications	Days between sprays
1	(*a*) Rotenone spray A, 1-500 + rosin residue emulsion 1-250	4	4
	(*b*) Bentonite 2 lb. to 40 gal. in 0.5% white oil emulsion	15	4
2	Fixed nicotine 4 lb. to 40 gal. in 0.5% white oil emulsion	19	4
3	Check—water	19	4
4	(*a*) Thiocyanate spray A, 1-1000 + soap 4/5 oz. per gal.	4	4
	(*b*) Thiocyanate spray A, 1-800 + soap 4/5 oz. per gal.	15	7
5	Fixed nicotine 4 lb. to 40 gal.	19	4
6	(*a*) Rotenone spray A, 1-500 + rosin residue emulsion 1-250	15	4

Weekly totals of chrysanthemum midge emergence

Date	Emergence and cage number					
	1	2	3	4	5	6
June 5–11	46	19	56	12	33	28
12–18	30	12	34	11	31	59
19–25	71	12	110	63	56	76
19–July 2	116	44	170	41	55	111
July 3– 9	123	35	111	43	48	71
10–16	85	45	93	20	63	28
17–23	131	43	162	31	72	35
24–30	37	22	49	1	51	14
31–Aug. 6	61	14	72	2	67	19
Aug. 7–13	79	21	83	9	70	64
14–20	39	22	44	10	49	48
21–23	8	8	13	1	26	18
Totals	826	297	997	244	621	571

Experiments 2, 3 and 4 offer a direct comparison between the two thiocyanates and show clearly the marked superiority of lauryl thiocyanate. For example, the total number of emergents following spraying with this material at a dilution of 1-400 (cage 8) and 1-800 (cage 11) were 2 and 0, respectively, while thiocyanate spray B at 1-200 (cage 10) and 1-400 (cage 7) resulted in 31 and 43 emergents, respectively. Still more marked was the difference in experiment 4, in which there were no emergents in cage 19 after spraying with lauryl thiocyanate while 235 adults emerged in cage 24 following the applications of thiocyanate spray B.

TABLE 2.—CONTROL OF THE CHRYSANTHEMUM MIDGE ON POTTED CHRYSANTHEMUMS IN CAGES—EXPERIMENT 2—FIRST SPRAY APPLIED FEBRUARY 9, 1941

Cage No.	Treatments	No. applications	Days between sprays
7	Thiocyanate spray B, 1-400 + spreader	4	4
8	Thiocyanate spray A, 1-400 + spreader 1-400	4	4
9	Check—water	4	4
10	Thiocyanate spray B, 1-200 + spreader 1-400	4	4
11	Thiocyanate spray A, 1-800 + spreader 1-400	4	4
12	Nicotine sulphate 1-800 + soap 4/5 oz. per gal.	4	4

Weekly totals of chrysanthemum midge emergence

Date	Emergence and cage number					
	7	8	9	10	11	12
Prior to spraying:						
Feb. 3–8	17	11	31	14	28	38
After spraying:						
Feb. 10–16	19	2	54	20	0	30
17–23	20	0	22	6	0	10
Total since spraying	39	2	76	26	0	40
Feb. 26–Mar. 4*	0	0	0	0	0	0
Mar. 5– 11	1	0	2	3	0	3
12– 18	3	0	17	2	0	0
19– 23	0	0	15	0	0	3
Total since Feb. 26	4	0	34	5	0	6

* Record from cuttings from treated plants transferred to smaller cages.

TABLE 3.—CONTROL OF THE CHRYSANTHEMUM MIDGE ON POTTED CHRYSANTHEMUMS IN CAGES—EXPERIMENT 3—FIRST SPRAY APPLIED MARCH 3, 1941

Cage No.	Treatments	No. applications	Days between sprays
13	Thiocyanate spray B, 1-400 + spreader 1-400	4	4
14	Thiocyanate spray A, 1-400 + spreader 1-400	4	4
15	Check—water	4	4
16	Thiocyanate spray B, 1–200 + spreader 1-400	4	4
17	Thiocyanate spray A, 1-800 + spreader 1-400	4	4
18	Rotenone-pyrethrum spray A, 1-400	4	4

Weekly totals of chrysanthemum midge emergence

Date	Emergence and cage number					
	13	14	15	16	17	18
Prior to spraying:						
Mar. 2– 3	20	24	17	10	12	10
After spraying:						
Mar. 4–10	26	1	129	7	1	26
11–17	20	0	105	6	0	44
18–24	52	0	88	23	0	66
Total since Mar. 4	98	1	322	36	1	136
Mar. 25–31*	0	0	—	—	10	—
Apr. 1– 7	0	0	—	—	40	—
8–14	0	2	—	—	93	—
15–19	0	0	—	—	12	—
Total since Mar. 25	0	2	—	—	155	—

* Record taking continued for cages 13, 14 and 17 from cuttings placed in smaller cages. Others discontinued.

NOTE.—In addition, the following partly emerged dead flies were recorded: 2 in cage 17 on March 13, and 6 in cage 14 on March 18.

TABLE 4.—CONTROL OF THE CHRYSANTHEMUM MIDGE ON POTTED CHRYSANTHEMUMS IN CAGES—EXPERIMENT 4—FIRST SPRAY APPLIED JANUARY 9, 1942

Cage No.	Treatments	No. applications	Days between sprays
19	Thiocyanate spray A, 1-400. Entire plant sprayed	3	3
20	Check—water	3	3
21	Thiocyanate spray A, 1-800. Entire plant sprayed	3	3
22	Thiocyanate spray A, 1-400. Only upper surface of plant sprayed	3	3
23	Thiocyanate spray A, 1-800. Only upper surface of plant sprayed	3	3
24	Thiocyanate spray B, 1-200. Entire plant sprayed	3	3

Weekly totals of chrysanthemum midge emergence

Date	Emergence and cage number					
	19	20	21	22	23	24
Prior to spraying:						
Jan. 2– 9	3	3	2	37	1	4
After spraying:						
Jan. 10–16	0	28	0	0	1	7
17–23	0	137	5	1	3	37
24–30	0	193	21	4	35	136
31–Feb. 6	0	78	19	3	55	55
Total since spraying	0	436	45	8	94	235

NOTE.—In addition the following partly emerged dead flies were recorded for the period January 10 to February 6, inclusive: Cage 19, 17; cage 20, 1; cage 21, 18; cage 22, 24; cage 23, 10; cage 24, 4.

Experiments 5 and 6 were carried out to determine the number of applications of lauryl thiocyanate necessary to give complete control. The results, given in Tables 5 and 6 show that in neither case did one application (cages 28 and 33) give complete control, although there was a marked reduction in emergence as compared to the check. In the case of two applications, complete control was secured in cage 26, while 4 adults emerged in cage 31. However, 3 applications gave complete control in both experiments (cages 25 and 30).

TABLE 5.—CONTROL OF THE CHRYSANTHEMUM MIDGE ON POTTED CHRYSANTHEMUMS IN CAGES—EXPERIMENT 5—FIRST SPRAY APPLIED MARCH 4, 1942

Cage No.	Treatments	No. applications	Days between sprays
25	Thiocyanate spray A, 1-400	3	3
26	Thiocyanate spray A, 1-400	2	3
27	Check—water	—	—
28	Thiocyanate spray A, 1-400	1	—
29	Thiocyanate spray A, 1-600	3	3

Weekly totals of chrysanthemum midge emergence

Date	Emergence and cage number				
	25	26	27	28	29
Prior to spraying:					
Mar. 2– 4	188	124	93	81	109
After spraying:					
Mar. 5–11	0	0	321	0	0
12–18	0	0	335	2	0
19–25	0	0	271	23	0
26–Apr. 1	0	0	*	18	0
Apr. 2– 8	0	0	—	8	0
Total since spraying	0	0	927	51	0

* Records discontinued on March 26 in cage 27.

TABLE 6.—CONTROL OF CHRYSANTHEMUM MIDGE ON POTTED CHRYSANTHEMUMS IN CAGES—EXPERIMENT 6—FIRST SPRAY APPLIED APRIL 1, 1942

Cage No.	Treatments	No. applications	Days between sprays
30	Thiocyanate spray A, 1-400	3	4
31	Thiocyanate spray A, 1-400	2	4
32	Check—water	—	—
33	Thiocyanate spray A, 1-400	1	—
34	Thiocyanate spray A, 1-600	3	4

Weekly totals of chrysanthemum midge emergence

Date	Emergence and cage number				
	30	31	32	33	34
Prior to spraying: Mar. 28–Apr. 1	110	44	62	81	37
After spraying:					
Apr. 2– 8	0	0	127	1	0
9–15	0	0	250	4	0
16–24	0	4	208	15	12
Total since spraying	0	4	585	20	12

NOTE.—In addition the following partly emerged dead adults were recorded for the period April 2 to 24: Cage 33, 4; cage 34, 8.

Action of Thiocyanate Spray A on Chrysanthemum Midge Larvae in the Galls

So far as the writer is aware, no insecticide, other than the fumigant methyl bromide, has been shown to kill any appreciable number of chrysanthemum midge larvae within the galls, at least at doses safe to the plant. During the course of experiments 1 to 6, it became obvious from the emergence records that lauryl thiocyanate did kill a large number of the insects in the galls. As these emergence records gave no direct evidence as to whether the larvae or the pupae were being killed, a number of galls from all treated plants in experiment 3 were carefully dissected on March 24. Living larvae could be distinguished by their whitish translucent colour (orange when mature); they always showed some spontaneous movement when left undisturbed for a minute or two, and in nearly all the heart beat was visible (the quickest method of detecting life). All larvae from the check plants and those treated with thiocyanate spray B or the rotenone-pyrethrum spray appeared normal, and were still making vigorous movements after 18 hours in a moist chamber, but all those examined from the plants treated with lauryl thiocyanate 1-400 or 1-800 were dead, and had begun to decompose after 18 hours. However, in certain of the thiocyanate treatments in experiments 1 to 6 a few adults emerged but died still attached to the pupal case, indicating that some pupae survived the treatment, but that the adults died when they came in contact with the treated surface. Also it will be noted in Table 3 that some adults eventually emerged from the plants which were examined, 2 adults emerging from cage 14 treated with lauryl thiocyanate 1-400, and 155 from cage 17 treated with the same spray diluted 1-800. The inference is that some larvae which are very small at the time the spray is applied are not killed. Other observations showed that at this season the period from egg to adult was about 47 days, which would imply that individuals which emerged between April 5 and 16 were about 1 week or less old when the first spray was applied, whereas those which failed to emerge prior to March 24, and presumably were dead by that date, were about 3 weeks old at the time of the first spray. In another test it was noted that from 17 to 22 days elapsed after egg laying before galls by the resulting larvae became visible, so this would explain why all the larvae treated with lauryl thiocyanate and examined on March 24 were dead, because larvae were removed only from visible galls.

Experiment 4 was carried out with the aim of determining how thoroughly the plants had to be covered with lauryl thiocyanate for effective control. The results, given in Table 4, show that, as would be expected, not nearly as effective control was secured when only the upper surface was sprayed. At a dilution of 1-400 complete control was secured when all surfaces were covered (cage 19), while 8 adults emerged from plants sprayed on the upper surface only (cage 22); similarly at 1-800, 45 adults emerged following complete coverage (cage 21), and 94 from upper coverage only (cage 23).

Thiocyanate Spray A as a Dip for Infested Chrysanthemum Cuttings

Two lots of 10 infested cuttings each were treated with thiocyanate spray A diluted 1-800, and similar lots with the same dilution plus a proprietary spreader.[3] Ten cuttings were left untreated as a check. Each cutting was moved up and down in the liquid for 10 seconds, then placed in moist sand in 8-inch flower pots covered with culluloid cages to record the emergence of adults. The daily emergence records are summarized for weekly periods in Table 7.

TABLE 7.—WEEKLY EMERGENCE RECORDS OF CHRYSANTHEMUM MIDGE ADULTS FROM CUTTINGS DIPPED IN THIOCYANATE SPRAY A ON MARCH 26, 1941

Date	Thiocyanate spray A 1-800		Thiocyanate spray A 1-800 + spreader 1-400		Check untreated
	Cage A	Cage B	Cage C	Cage D	
Mar. 27–Apr. 2	0	0	0	0	8
Apr. 3– 9	0	0	12	6	50
10– 16	1	0	12	7	92
17– 19	0	0	1	1	5
Total	1	0	25	14	155

These dips corresponded to one spray application so it was rather surprising that at the dilution of 1-800 almost a complete kill was obtained when no spreader was used (cages A and B). As this test was on too small a scale to be sure that the difference due to the spreader was significant, it will be repeated. It is possible that the added spreader results in a smaller deposit of the insecticide and thus lowers its efficiency. It should be mentioned that this insecticide carries its own spreader and at the dilution of 1-600 wets the foliage quite well but at 1-800 some difficulty is experienced in getting complete coverage unless additional spreader is added.

OVICIDES FOR CHRYSANTHEMUM MIDGE EGGS

Chrysanthemum midge eggs are small and usually laid in clusters in plant crevices so that it is difficult to count them or to distinguish between hatched and unhatched eggs. It was therefore not found practicable to make any very precise experiments with ovicides, but a few tests were carried out in which the effect on the eggs was determined indirectly by the formation of galls from the larvae which hatched from treated eggs. Small potted chrysanthemums were exposed to the adults for one or two days and the insecticides applied when the eggs were 2 or 3 days old. The

[3] Lethane spreader.

plants were then caged to prevent reinfestation and notes taken on gall formation. Unless a material happened to be 100% effective only a very approximate idea of the ovicidal action was obtained.

The insecticides tested were: (1) Rotenone spray B, 1-400; (2) rotenone spray C, 1-400; (3) rotenone-pyrethrum spray A, 1-400; (4) thiocyanate spray A, (lauryl thiocyanate), 1-600 and 1-400; (5) thiocyanate spray B, 1-400 and 1-200; (6) nicotine sulphate (7) 1-600 plus 0.5% soap; and free nicotine (7) 1-600 plus 0.5% soap. The first test was started on February 21, and repeated on new lots of plants and eggs on March 31 and again on April 13, 1941.

The results showed that thiocyanate spray A (lauryl thiocyanate) at 1-400 and 1-600 gave 100% control, almost undoubtedly by direct action on the eggs rather than residual action on hatching larvae, because microscopic examination showed the eggs to be shrunken and apparently unhatched. None of the other materials gave complete kill, although thiocyanate spray B apparently killed a very high percentage because only 6 galls developed on the treated plants as compared with more than 100 on the checks. The other materials gave varying degrees of control which in most cases resulted in a reduction of approximately 50% in the number of galls as compared with the checks.

TIMING OF SPRAYS FOR CHRYSANTHEMUM MIDGE CONTROL

Spray recommendations for the control of this pest are usually accompanied by some statement such as "for best results apply late in the afternoon or evening," the object being to prevent loss of effectiveness on the foliage until after the flies start emerging at midnight. In order to find out how long nicotine and rotenone-pyrethrum type insecticides retained their effectiveness after being applied, different lots of infested plants were sprayed at 10 a.m., 2, 4, 7 and 10 p.m., respectively on an open bench and at 10 p.m. placed in cotton cages from which emergence records were taken daily at 8 a.m.

Two series of tests were run with nicotine sulphate 1-600 and two series with rotenone-pyrethrum spray A 1-400, and the results are given in Tables 8 to 11, inclusive.

TABLE 8.—EMERGENCE RECORDS FOLLOWING SPRAYING WITH NICOTINE SULPHATE 1-600 AT DIFFERENT HOURS OF THE DAY—FIRST TEST

Date	Time of spraying and adult emergence					
	10 a.m.	2 p.m.	4 p.m.	7 p.m.	10 p.m.	Check
Before spraying:						
Jan. 24	5	12	7	1	5	3
25	7	16	13	18	9	3
26	12	15	9	15	6	3
27	18	34	15	24	9	12
After spraying:						
Jan. 28	1	1	1	1	0	17
29	0	3	1	5	2	19
30	6	15	7	13	7	18
31	3	19	4	11	9	20
Feb. 1	7	30	5	15	4	20
2	9	25	11	18	19	21

TABLE 9.—EMERGENCE RECORDS FOLLOWING SPRAYING WITH NICOTINE SULPHATE 1-600 AT DIFFERENT HOURS OF THE DAY—SECOND TEST

Date	Time of spraying and adult emergence					
	10 a.m.	2 p.m.	4 p.m.	7 p.m.	10 p.m.	Check
Before spraying:						
Feb. 9	37	35	20	24	44	13
10	40	42	42	26	41	23
After spraying:						
Feb. 11	1	1	0	0	0	18
12	3	5	6	2	12	25
13	18	17	16	8	32	16
14	37	16	37	10	20	9
15	No record					
16	29	22	34	15	23	21
17	17	22	30	16	14	15

TABLE 10.—EMERGENCE RECORDS FOLLOWING SPRAYING WITH ROTENONE-PYRETHRUM SPRAY A 1-400 AT DIFFERENT HOURS OF THE DAY—FIRST TEST

Date	Time of spraying and adult emergence					
	10 a.m.	2 p.m.	4 p.m.	7 p.m.	10 p.m.	Check
Before spraying:						
Jan. 31	3	19	4	11	9	20
Feb. 1	7	30	5	15	4	20
2	9	25	11	18	19	21
3	15	33	29	30	30	36
After spraying:						
Feb. 4	1	0	0	0	0	28
5	7	4	2	2	1	28
6	13	11	3	5	10	12
7	24	13	7	8	16	9
8	No record					
9	37	35	20	24	44	13
10	40	42	42	26	41	23

TABLE 11.—EMERGENCE RECORDS FOLLOWING SPRAYING WITH ROTENONE-PYRETHRUM SPRAY A 1-400 AT DIFFERENT HOURS OF THE DAY—SECOND TEST

Date	Time of spraying and adult emergence					
	10 a.m.	2 p.m.	4 p.m.	7 p.m.	10 p.m.	Check
Before spraying:						
Feb. 16	29	22	34	15	33	21
17	17	22	30	16	14	15
18	45	43	29	24	35	19
19	18	12	20	18	18	8
20	30	22	19	12	27	17
After spraying:						
Feb. 21	9	2	3	0	0	23
22	36	16	25	5	14	24
23	16	27	25	13	22	19
24	19	31	32	16	27	24

It is evident that under the conditions of this experiment there was little difference in the reduction of emergence by the sprays applied at different times of the day, although the 10 p.m. spray was the only one which gave complete control for 24 hours in all cases. In the first test with nicotine sulphate one fly emerged within 24 hours in all cages except that sprayed at 10 p.m., while in the second test only the 10 a.m. and 2 p.m. sprays resulted in survivors. There was a similar variation in the case of the rotenone-pyrethrum spray, the first test showing complete control for 24 hours in all cages except that sprayed at 10 a.m., while in the second test this resulted only in the 7 p.m. and 10 p.m. cages. A number of dead flies which had apparently died shortly after emerging were recorded from all the cages, but almost invariably the number was less than that required to bring the total emergence up to the expected normal. This would imply that the insecticides tended either to lengthen the pupal period or to kill some pupae.

These data also bring out the fact that one application of either of these insecticides kept the daily emergence below normal for a period of 48 to 72 hours, although the unevenness of the daily emergence before spraying and in the unsprayed checks made it difficult to determine just when normal emergence was resumed.

The conclusions suggested by the above experiment in connection with the use of nicotine sulphate or rotenone-pyrethrum type sprays are (1) that eradication would be effected more quickly if spraying were done every day rather than every second or third day, and (2) that it is advisable, but not essential, to apply the sprays late in the day or during the evening. However, it is quite possible that during the warmer spring and summer months when evaporation would be more rapid, spraying late in the evening would be relatively more effective than earlier in the day, as compared to the results given here for January and February.

MIDGE CONTROL WITH LAURYL THIOCYANATE UNDER COMMERCIAL CONDITIONS

The writer has had the opportunity of testing lauryl thiocyanate for midge control twice on the chrysanthemums at the Horticultural Experimental Station at Vineland Station, and of observing the results in a large commercial greenhouse.

Starting the last week in March 1941, four applications at 4-day intervals, followed by 5 applications at from 1- to 2-week intervals of thiocyanate spray A 1-800 plus a commercial spreader, were made on the Experimental Station plants which had been started from cuttings in January and February. Observations showed that after the first 2 or 3 sprays there was little apparent development of the midge, and that by September almost all the plants were completely free of midge. A few new galls and a few eggs were found on 3 or 4 plants later in the fall, but it is not certain whether these came from survivors of the treatment or from the heavily infested plants in a near-by compartment.

In December these plants were cut back and a moderate infestation developed on the new growth, so starting on December 26 the following spray schedule was applied, using a power sprayer at about 250-lb. pressure

and at an air temperature of approximately 60–65° F.: Thiocyanate spray A 1-400 for 3 applications at 3-day intervals followed by 3 applications at weekly intervals at a dilution of 1-600.

The results were very similar to those obtained from the treatment the previous year. After the first 2 sprays midge development apparently stopped, and all the cuttings taken in February appeared to be clean. However, early in June, 4 new galls were found on one plant, but up to the time of bloom in October there was no visible increase in the infestation. In November it was found that some of the new shoots growing from the base of the plants were moderately infested, but again it cannot be said whether or not this resulted from reinfestation from the adjoining entomological greenhouse. Nevertheless, it was clearly shown that midge infestation can be held to insignificant proportions by the foregoing treatment.

Starting February 21, 1941, a commercial grower carried out the following control schedule: Lauryl thiocyanate spray 1-400 plus a spreader for 4 applications at 3-day intervals, followed by a fourth application 2 weeks later at a dilution of 1-600 plus the spreader. The plants at this time were in the "stool" stage, prior to taking cuttings. Growth was fairly dense but an attempt was made to hit all parts of the foliage with the spray, but it is thought that some of the undersides of the lower leaves were missed. An examination of the plants in April showed that only partial control had been secured. Cuttings taken from the treated plants on April 3–6 seemed to be entirely free of midge, but a few eggs could be found on some of the new shoots on the stools. Two more sprays at a dilution of 1-600 were applied in May, but these failed to eliminate the infestation, although it was much less than in previous years.

The conclusion to be drawn from these large scale tests is that the failure of the short spray schedule to effect eradication is probable due to the difficulty of obtaining complete coverage of the low-lying plants. Further tests are to be carried out in 1943 in which a few additional applications will be made and more attention paid to getting complete coverage.

SUMMARY

From 1 to 4 applications, at 3- to 4-day intervals, of a spray containing lauryl thiocyanate as the active ingredient were shown to be more effective in controlling the chrysanthemum midge than a corresponding number of applications of either nicotine sulphate, free nicotine, normal butyl carbitol thiocyanate, rotenone-bearing insecticides or white oil. Lauryl thiocyanate was also the only material of those tested which killed most of the larvae in the galls. As an ovicide, lauryl thiocyanate spray diluted 1-600 and 1-400 was 100% effective, while other materials tested gave a lower kill.

Under cage conditions, 4 applications of the lauryl thiocyanate spray diluted 1-400 almost invariably gave complete control when all parts of the plants were covered with the spray. Incomplete control resulted when (*a*) the coverage was not complete, (*b*) less than 4 applications were made, or (*c*) the dilution was reduced to 1-800.

In large scale tests on plants on an open bench, not quite complete control resulted from a spray schedule of lauryl thiocyanate of 4 applications at a dilution of 1-400 followed by 4 applications at weekly intervals

at a dilution of 1-600. A commercial grower following a similar schedule also failed to get 100% control. The fact that control was slightly less than complete under the open bench conditions is attributed to the failure to get complete coverage of all parts of the plants. Three or 4 additional applications at weekly intervals at a dilution of 1-600 are therefore recommended, with instructions to use more spray and to be sure the undersides of the leaves are hit by holding the spray nozzle about 6 inches from the plants and at an angle pointing upward, and also to cover the upper surface thoroughly.

The best time to treat chrysanthemums with lauryl thiocyanate for midge control is during the winter after the plants are cut back and before the cuttings are made, because at this season there is less foliage to cover and any slight injury which may result from the insecticide will be quickly outgrown.

ACKNOWLEDGMENT

The dissections of chrysanthemum midge galls on March 24, 1941 were carried out by Mr. W. L. Putman, to whom the writer wishes to express his thanks.

NOTES ON COMMON MILKWEED[1]

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This paper is based on records which have accumulated over many years and which may be found useful by others now interested in the utilization of milkweed. Common milkweed (*Asclepias syriaca* L.) is one of about a dozen species and varieties native of Canada which was studied because of its importance as a weed.

DISTRIBUTION AND INCIDENCE

According to the manuals common milkweed ranges from New Brunswick to Saskatchewan and southward. In Canada this range was extended to Nova Scotia when it was discovered near Avonport in 1930 (1). Several colonies in the Annapolis valley are now known. To the west the range to "the Saskatchewan" (2) extends from Ontario south, but not north, of the upper Great Lakes. It is absent from the whole Canadian Shield, east and west, except for occasional outliers along its southern fringe, as at North Bay and around the Mont Laurier "loop" above Montreal and Ottawa. Distribution can be correlated rather well with the cleared portion of the mixed forest, together with the Carolinian vegetation belt, of North America (3). Outliers in the Canadian life zone may be nothing more than river valley intrusion from the Transition zone, i.e. along the St. John and Restigouche rivers and Ottawa tributaries from the north.

The 125 specimens available in several eastern herbaria, but mostly at the Division of Botany, were considered to be an adequate basis for the foregoing statement of distribution in Eastern Canada, but were too few to throw much light on incidence. For this purpose records from more than 2700 weed surveys east of Lake Superior are used (Figure 1). In Table 1 each figure for percentage represents the number of survey lists, of 100 secured, in which milkweed was one of the species recorded. From belts of three degrees longitude a curve can be recognized here which shows a distinct peak of incidence in eastern Ontario. Each end terminates in Canadian zone absence of records (although southern Ontario incidence would be maintained westward through Michigan).

TABLE 1.—CANADIAN WEED SURVEY PERCENTAGE INCIDENCE. COMMON MILKWEED

84° West Superior region	83 – 81° S.W. Ont.	80 – 78° Toronto region	77 – 75° E. Ont.	74 – 72° E. Tps. Que.	71 – 69° Quebec region	68 – 66° W.N.B. & adj. Que.	65 – 63° E.N.B. & W.N.S.	62 – 60° E. N.S.
%	%	%	%	%	%	%	%	%
0	53.3	51	75.3	71.9	20.5	10.9	1	0

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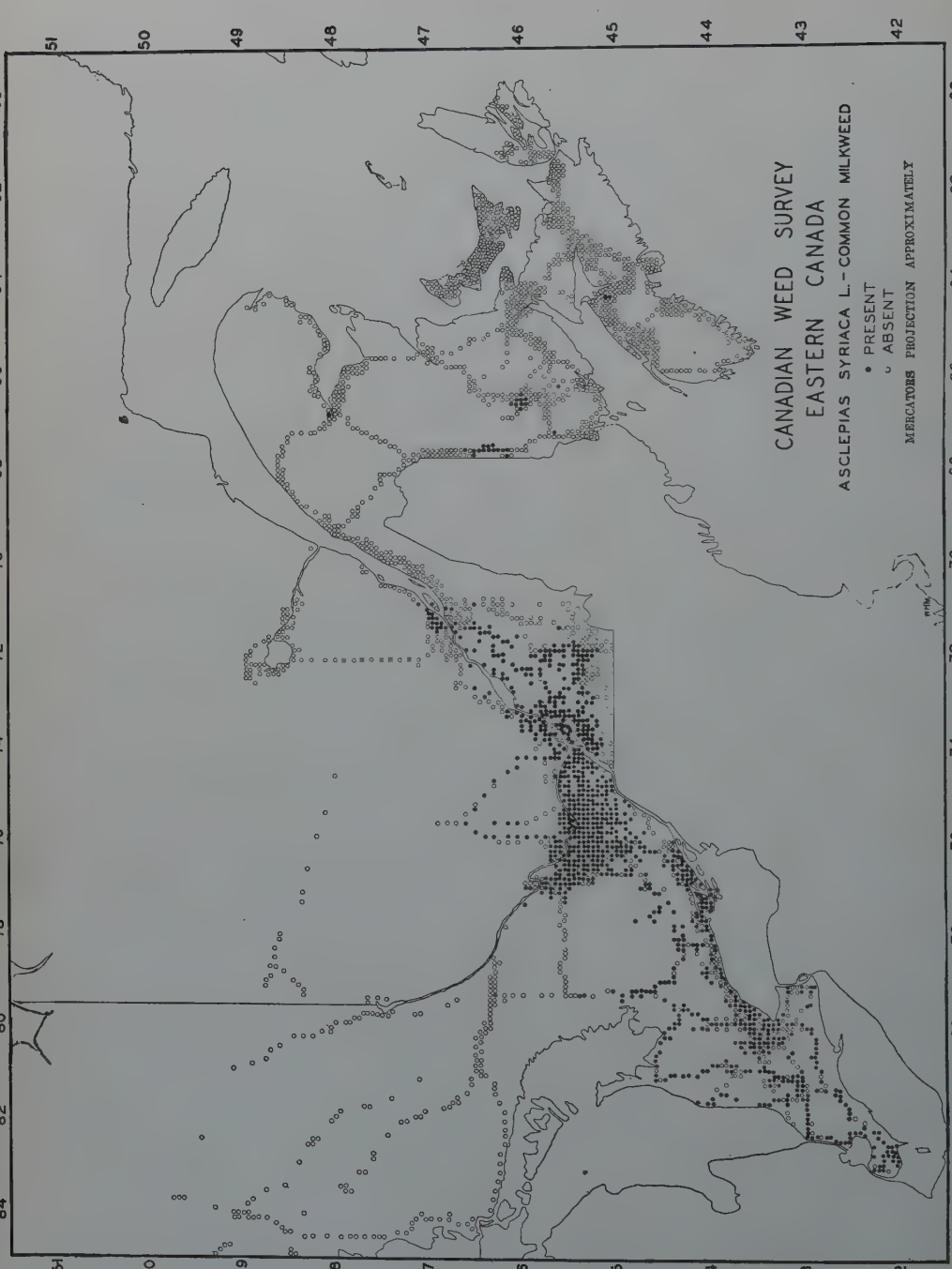

FIGURE 1. Distribution of common milkweed in Eastern Canada.

Proceeding to a closer analysis of the data by latitude as well as longitude (Figure 2) it can be shown that along most of the Quebec-Ontario axis an inner belt of greater incidence appears. Mostly south of a line from Three Rivers, Que., to Ottawa, Ont., this becomes a peak or double peak. A second peak or double peak is evident south of Georgian Bay and eastward, and a third across the lower peninsula of Ontario. Use of isobars visualizes highs and lows of incidence. The result may be only broadly true to the facts as they would be disclosed by an intensive and systematic survey, but it could be some guide to such survey. Only a close examination by township, concession or lot will uncover fluctuation of density or abundance and the various reasons for it. Topography, soils and other variables may be expected to have a bearing on milkweed population.

Without such further surveys it is safe to say that milkweed is not a weed of the wooded Canadian zone and Precambrian Shield; nor is it at peak incidence in the intensively farmed counties along Lake Ontario and inland in the southwestern peninsula. Most of the belt of greater incidence may well reflect a larger percentage of the cleared land under pasture and idleness owing to more broken topography. Milkweed is distinctly a plant of the open although not extremely tenacious in cultivated land. It is commonly in sod, although there is some indication that a point in the history of a sod may be reached beyond which invasion is followed by decline. This, along with soil relationship needs closer study and survey.

Some greenhouse tests of a few of the various soils in which milkweed is found growing around Ottawa gave best development of seedlings in loam and muck and poorest in clay and sand (Table 2).

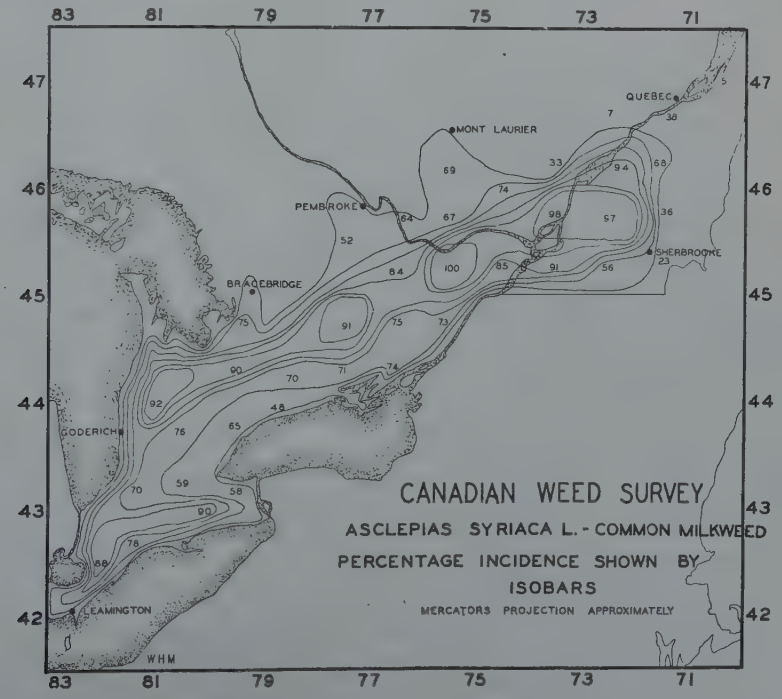

FIGURE 2. Percentage incidence of common milkweed in Ontario and Quebec.

TABLE 2.—COMMON MILKWEED AFTER FOUR MONTHS (TEN SEEDLINGS)

	Clay	Sand	Muck	Loam
Height of stem	2 in.	2½ in.	4½ in.	5¾ in.
No. of leaves	7 pairs	9 pairs	16 pairs	17 pairs
Length of leaves	Under 2 in.	Under 2 in.	2½ in.	3½ in.
Nature of root	Slender	Slender	Stout	Stout, densely fibrous

In nature milkweed plants were found growing in all of these as well as over limestone and in limestone talus. Acid tolerance, where tested, varied between pH 6.6 and pH 5.7, or from slightly to medium acid. Further tests might determine whether the decrease of milkweed eastward and westward is correlated with more extreme soil reactions.

MISCELLANEOUS EXPERIMENTS

Propagation by Root Sections

In order to gain information on this means of spread 75 pieces of root 3, 6, 12 and 18 inches long were planted at a uniform depth of 6 inches. At the date of planting, May 19, young shoots up to 1¼ inches long had started growth but most of the larger ones were broken off in the handling, and appearance of shoots above ground was retarded about a week as compared with undisturbed plants. On June 6, 18 days from planting, shoots were appearing from 12 and 18-inch pieces, but at one month only a few had come through from 3- and 6-inch pieces. After another 24 days more shoots had appeared from the short pieces but these lagged behind those from longer pieces, which were now beginning to flower, while undisturbed milkweeds were in full bloom.

Nearly 3 months after planting, digging of the 50 3-inch pieces disclosed that 10% were completely rotted, the rest growing, and 36% of the total number had reached the surface and up to 3 inches above.

The 25 pieces of other lengths were dug at 4 months and proved to be sound with the exception of 2 of 6 inches and most of 1 of 12 inches. Without exception the sound pieces of all 3 lengths had produced 1 shoot each, those from 6-inch pieces being distinctly behind the others in length. Table 3 gives further particulars.

TABLE 3.—MILKWEED ROOT SECTIONS PLANTED

No. of pieces	Length of pieces	Viability	Height of stalk	No. of leaves	Fruit	Order of appearance
	in.	%	in.	pairs		
50	3	90	3	5	None	4
10	6	80	7.5	6 – 7	None	3
10	12	90	14 – 21	8 – 10	2 follicles seed immature	2
5	18	100	14 – 21	10 – 11	4 follicles seed ripe	1

Although many buds were formed on a root section only 1 grew to the surface and bore foliage. Buds from a root placed upside down curved upwards in obedience to a negative geotropism. Shoots and the resulting stalks above ground were directly proportional in size to the size of the roots planted, as well as being related to their length. While sections of all lengths may produce plants it is evident that longer sections produce stronger plants many of which are able to bloom and mature seed in the same season. Shoots before reaching light are similar, except in absence of green colour and foliage, to stalks above ground; and contain latex in all parts, while this is absent from roots.

Root Histories

During 3 years, observations were made on the development of 4 root sections, 12, 14, 29 and 55 inches in length at the time of transplanting on May 9, 1931, and bearing respectively (?), 13, 23, and 42 buds. A fifth root was lost in hot, dry weather after reaching flowering stage in July. After 1 year they were carefully dug up, examined and re-planted. On July 27, 1933 they were again examined and discarded. Each year notes were made on above-ground growth.

The original pieces remained about constant in length except the 2 longer which were reduced to 22 and 45 inches respectively at the end of the period. To each section were added new roots totalling in length for the 12-inch root, 183 inches; 14-inch, 99 inches; 29-inch, 129 inches; 55-inch, 130 inches; an average of about 135 inches each, without obvious relation to original length.

The number of buds, originally in some relation to length of root-piece, increased somewhat in keeping with development of new roots, but records are incomplete. The number and average height of shoots from these buds was greatest where total length of old and new roots was greatest—as it happens, from the shortest original section. Difference between the other 3 was slight. In other respects this short section led each of the others, and most of all in producing 43 follicles in 1932 and 1933 as against 14 for the nearest competitor. From this, as from the experiments in propagation, it would appear that a 12-inch section is long enough for maximum development.

Seedling Histories

Seed was collected from old stems of 2 of the roots transplanted on May 9, 1931—the 1 lost during that season and the 12-inch section. Twenty seeds of each sample were sown alongside the corresponding root-piece, and produced respectively 12 and 3 surviving seedlings. By Sept. 3 the shoots were about 4 inches high with 9 or 10 pairs of leaves each. All roots had put forth shoots by May 18, 1932; and on Sept. 15 were represented by 15 shoots 10 to 28 inches high in the first instance, and 4 shoots 5 to 25, 27 and 32 inches high in the other. On May 18, 1933, the number of shoots was 10 and 13 respectively, a reversal from the previous year. On July 27 descriptive notes were made from 3 plants representative of the 2 sources but without retaining identity. Table 4 gives these particulars, and their averages, which may be taken as about normal for milkweed the second year from seed in otherwise bare plots on rather clayey soil.

TABLE 4.

Plant	Stalks		Umbels	Pods	Roots		Buds on roots
	No.	Height			No.	Length	
		in.				in.	
1	2	24, 24	1 + 1	2 + 3	4	63	6
2	4	25, 26, 26, 26	2 + 0 + 0 + 0	3 + 0 + 0 + 0	2	70	22
3	4	35, 28, 26, 24	3 + 2 + 0 + 0	4 + 2 + 0 + 0	3	81	8
Average	3½	26.3	3	4⅔	3	71⅓	12

Propagation by Seed

In any milkweed colony perhaps a majority of the stalks will be found to be sterile. Those bearing one or more umbels of flowers may produce from 1 to numerous follicles or so-called pods but never a high proportion of the total number of flowers in the umbels. Examination of 125 stalks with 2 to 18 pods each, showed 3 to 6 pods each on 81 stalks, or 65% of all.

Counts of the number of seeds per pod showed from 109 to 223 in each of 41 pods, or commonly from 160 to 220, an average of 188. These plants were from a half-dozen stations throughout the Ottawa district representing a variety of habitats.

Computing 190 seeds per pod and 4 pods per stalk, there would be 760 seeds per stalk. An estimate was made of 50,000 stalks per acre (this might be high anywhere else in Canada), 50% producing fruit, and yielding a result of 19,000,000 seeds per acre. Germination up to 80% or more is not unusual; therefore the numbers of viable seeds might reach as high as 15,200,000 per acre—infestation being at its worst. It is not to be expected, however, that seeds will all reach an environment favourable for germination, or that their seedlings will all survive. Wind, water and other agencies of dispersal act promiscuously, and among other things may deposit the seed where root propagation is already fully utilizing growing space for milkweed.

The "floss" attached to the seeds has shown some promise, in wartime research, as a substitute for Kapok. From data supplied by H. A. Senn of this Division, showing an average weight per pod of 3.73 grams of which roughly one-third is "floss", a natural stand of milkweed such as that just considered should yield 275 pounds of "floss" per acre. Grown as a crop to fully occupy the ground much greater yields would be possible.

Seed Germination

The following results are from a seed germination project, now in its tenth year, which includes the more important weeds of the Ottawa district.

The seeds to be tested were collected when the pods were opening for seed dispersal. They were cleaned promptly and spread thinly to dry without artificial heat. After about a week of exposure to the fairly high temperature of the laboratory they were put into 2 types of storage, paper envelopes, and tightly stoppered glass jars, to be kept in the laboratory for the duration of the experiment. The viability tests were made on top of moist blotters in a 20° to 30° C. germinator.

At maturity or a few days after collections, the seeds of common milkweed germinated poorly as compared with seeds of swamp milkweed (*Asclepias incarnata* L.) which germinated as much as 90% (Table 5). After storage for 1 year common milkweed seeds responded much better and maintained a similar level for a number of years, but not for as long nor at as high a level as swamp milkweed, both being stored in jars.

The desiccation occurring in envelope storage is evidently injurious to milkweeds, although with certain other species storage in envelopes has given results equalling or better than those from storage in glass. Milkweed viability, never as high from envelopes, declined sharply several years ahead of that from glass storage.

TABLE 5.—VIABILITY OF TWO SPECIES OF MILKWEED SEEDS WHEN STORED IN BOTTLES AND IN ENVELOPES

Interval	Common milkweed *Asclepias syriaca*		Swamp milkweed *Asclepias incarnata*	
	Stored in glass jar	Stored in envelope	Stored in glass jar	Stored in envelope
	%	%	%	%
Approx. maturity	2	8	85	90
1 year	71	42	84	72
2 years	32	12	85	47
3 years	86	31	96	48
4 years	79	36	97	16
5 years	84	6	99	2
6 years	74	5	95	0
7 years	62	8	98	
8 years	18		2	
9 years	32		3	

Milkweed Eradication

Beginning in 1931, experiments on eradication were carried out in a pasture field heavily infested at the outset. By 1935, however, it was apparent that experimental results were being vitiated by the progress of independent decline of the milkweed population related no doubt to change in the sod environment. Only some broad deductions from the data are, therefore, presented.

Preliminary trials of cutting, pulling, etc., were not encouraging. Field scale use of implements, if found efficient, would also be more economical of labour.

Iron sulphate spray, using 2 pounds to 1 square rod, destroyed the tops. Fresh growth, following a June 15 spraying, was destroyed by a second on July 21, but no appreciable difference to the stand was apparent in the following year.

Sodium chlorate received more extensive tests. Use of a 10% solution gave practically as good results as 20% or 30% solutions as recorded that year and the next. Two sprays each year for 2 years, using a 10% solution, gave a fairly satisfactory control of about 90% reduction of stalks. The first spray was applied early in July when the plants were in full bloom.

Without the second spray results were somewhat poorer, but still fair. Even if these results can be duplicated regularly there still remains the problem of cost for any more than patch use.

ACKNOWLEDGMENTS

Grateful acknowledgment is made of the assistance of those associated with the author, Messrs. W. G. Dore, W. H. Minshall and E. G. Anderson, whose large participation in the work and ample records have made possible this review. The maps were prepared by Dr. Minshall from records provided.

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ERRATUM

In the May 1943 issue of *Scientific Agriculture* (Vol. 23, No. 9), in the article "The Effect of Tartar Emetic on the Greenhouse Leaf-tyer, *Phlyctaenia rubigalis* Gn.", by G. G. Dustan, reference No. 1, page 527, was omitted and the following should be added to this article:—

1. Burdette, C. R. Results of two years work with an attractive spray for corn ear worm moth (*Heliothis obsoleta* Fab.). J. Econ. Ent. 27 : 213-217. 1934.